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Compressed Air Magazine

MARCH 1946

ROCK DRILL OF LAST CENTURY

1885 model of air-drive tool that has served as con struction spearhead

VOLUME 51 • NUMBER 3

NEW YORK • LONDON

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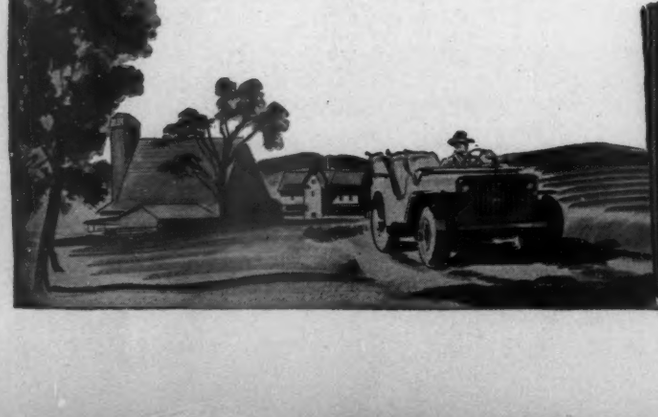
Write for Bulletin 135-10. Coppus Engineering Corporation, 443 Park Avenue, Worcester 2, Mass. Sales offices in THOMAS' REGISTER. Other Coppus "Blue Ribbon" products in SWEET'S.



ANOTHER

COPPUS

"BLUE RIBBON" PRODUCT

ON THE COVER

ALTHOUGH it has been stated many times, the contribution the rock drill has made to the advance of civilization is so important that it cannot be overemphasized.

Many industries, including some of the largest ones, depend entirely upon the excavation of ore or rock for their raw materials. Our transportation systems—railroads, highways, canals, and ship channels—would inevitably follow longer and more circuitous routes had their builders been obliged to attack rock solely with the power of human muscles. Our great dams and hydroelectric plants, our deep-rooted skyscrapers, our water-supply and sewage systems, and numerous other physical works that affect our daily lives and well-being exist largely because of the rock drill.

The list might be extended indefinitely. If we consider that no rock drill had been invented a century ago—that drills of practical worth were not built until around 1870—and reflect upon the tremendous progress that has been made during the intervening years, then we can get a true idea of how much we owe to this labor-saving tool.

Our cover picture shows a rock drill of about 1885. It was of the piston type, in which the drilling bar was rigidly attached to the piston, and it was much heavier than present models of equal power. Nevertheless, it greatly multiplied the work that one man could do by hand. Save for minor details, the column on which it was mounted could pass for a modern one.

•

IN THIS ISSUE

WE HAVE brought together in this anniversary edition salient facts about the history and applications of compressed air. The information presented has been printed previously piecemeal, but this is the first time it has been collated. We hope the issue will have lasting value as a reference source.

Compressed Air Magazine

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VOLUME 51 **March, 1946** NUMBER 3

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OUR FIRST FIFTY YEARS

Compressed Air
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Vol. I. New York, July, 1896. No. 5
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Subscription One Dollar a year; 10 cents a number
Advertising rates furnished on application.
We invite correspondence from engineers, contractors, inventors and others interested in compressed air.
All communications should be addressed to COMPRESSED AIR, 26 Cortlandt St., New York.
Those who fail to receive papers promptly will please notify us at once.
MARCH, 1896.
The air we innocently breathe inspires life's onward course, compressed it stands a latent power, expanding it becomes a mighty force.

MEMENTOS OF 1896

The masthead of our first issue appears directly above. At the upper right is a reproduction of the cover of the fifth issue, July, 1896. A subscription blank that was used in that period is shown at the upper left.

COMPRESSED Air Magazine was started in March, 1896, by William Lawrence Saunders who believed that pneumatic power had become important enough to warrant a publication of its own. It was then and has remained the only magazine in the United States in its field. In its early form it was made up largely of articles reprinted from other trade papers, supplemented by editorial comment and an occasional staff-written piece. That policy was continued until 1919, and from that time on all reading matter has been written for original publication in these pages. The magazine has never missed a monthly issue.

In its initial format the publication was 5½x8¼ inches in size, and this was increased to 6¾x9¾ inches ten years later. In 1920 it assumed its present proportions, which have been maintained save for some minor trimming necessitated by the paper shortage during the late war. At the outset its name was simply COMPRESSED AIR, the word "magazine" having been added in 1908.

After the fledgling journal had attained an age of ten issues, the editor reviewed its progress as follows: "We do not claim we have prospered much, but we think we have learned a good deal and, among other things, it is clear that this paper is an established and permanent success." By 1909 he apparently felt that the magazine had really "arrived," for he exuberantly characterized it as "A journal of progress in applied pneumatics, dealing with practical applications of compressed air for every purpose and in every field. A monthly digest of world's literature on compressed air. The busy man's compendium of compressed air information; always up to date and recognized everywhere as the highest authority in its field." Mr. Saunders was a successful industrialist in the field of compressed-air manufacturing, and editing the magazine was but an interesting side line with him. His affiliation with compressed-air power dated from 1879, when he became an engineer for the National Storage Company at Communipaw, N. J. His work involved directing the construction of piers and warehouses, as well as excavating a ship channel from the main New York Harbor fairway to Black Tom Island near the New Jersey shore. Rock, overlain by gravel and hardpan, was encountered, so he put on a diver's suit and went down to inspect it, although he had had no previous experience in that line. Three years before, at the Centennial Exhibition in Philadelphia and while a senior in college, he had shown a similar fondness for adventure by going aloft in a balloon with Samuel A. King, then a famous aeronaut.

The channel situation called for underwater drilling and blasting, so air drills were brought in and operated under Mr. Saunders's supervision. This gave him an interest in pneumatic machinery that determined the course of his life. He went to work for the Ingersoll-Sergeant Drill Company in 1881 and was chairman of the board of directors of its successor, Ingersoll-Rand Company, at the time of his death in June, 1931.

In establishing the magazine, Mr. Saunders was indulging an inclination to write that had cropped out before. He received an engineering degree from the University of Pennsylvania in 1876, but engaged in newspaper work and special writing for two years thereafter, having previously whetted his authorship appetite by editing his school's magazine and serving as class poet. In later life he became a public speaker of some renown and often addressed engineering societies and colleges. He served as president of the American Institute of Mining & Metallurgical Engineers and established the W. L. Saunders medal that is awarded annually by that organization.

Although a Democrat, he perhaps touched off the spark that lighted the way for Herbert Hoover's trip to the White House. The occasion was a dinner given to Mr. Hoover on September 16, 1919, by 1300 fellow members of the A.I.M.M.E.

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EARLY ADVERTISEMENTS

Two of our current advertisers have been with us just one month short of 50 years, their initial advertisements, which are reproduced here, having appeared in our April, 1896, issue. The firms are: The Manhattan Rubber Manufacturing Division of Raybestos-Manhattan, Inc., of Passaic, N. J., and Chas. A. Schieren Co., of New York.

upon his return from five years of directing American war-relief activities in Europe. Mr. Saunders was the toastmaster, and in introducing Mr. Hoover he said: "The engineer is by education and experience the true captain of industry, fitted to handle the ship of state." There was great applause, and the Hoover boom was underway.

Mr. Saunders edited COMPRESSED AIR MAGAZINE until January, 1920, a period of almost 25 years, or half its present life span. During the early years he did much of the detail work and solicited advertising. Later on, when his time became heavily occupied with other affairs, he still looked over and approved all editorial matter prior to its publication. In 1900, Frank Richards, who had previously been on the staff of the *American Machinist*, joined the force, and during the ensuing years he assumed a large share of the editorial duties. The magazine was published by Mr. Saunders until July, 1907, when the Compressed Air Magazine Publishing Company was formed. Mr. Saunders became its president following his retirement as editor. The company was incorporated in New Jersey in 1932.

Francis J. Tietsort succeeded Mr. Saunders as editor and served from January, 1920, until April, 1921, when Eugene P. McCrorken took over the post. In January, 1923, Robert G. Skerrett began a 10-year period as editor and has, since his retirement in 1932, been a consistent contributor. He was followed by the incumbent, C. H. Vivian. Miss Anna M. Hoffmann, assistant editor, has held that position since October, 1922.

Probably the magazine's leading editorial effort to date was the description of the construction of Boulder Dam, 1931-35. All phases of that monumental work were covered in 21 articles, which exceeded the treatment given it in any other publication. The articles were afterward reprinted in the form of five booklets.

In concluding this summary of half a century of boosting the cause of air power, we can do no better than repeat a passage that we printed in March, 1935, when we began our fortieth year: " 'Compressed air, as a useful power, demands attention,' Mr. Saunders wrote in his first issue. 'Its scope of usefulness is each day widening, and its possibilities are beyond conjecture.' Compressed air has received the attention that he claimed for it. Otherwise his words are still as true as they were when he set them down. Compressed air is finding new applications all the while, and its possibilities remain beyond conjecture."

HOW ELECTROPNEUMATIC CHIME RINGING STARTED

BACK in 1897 a group of parishioners of St. Patrick's Cathedral in New York presented the church with a set of chimes, imported from France. It consisted of nineteen bells weighing individually from 165 to 6300 pounds and aggregating 15 tons. They were hung in the northern spire, but no provision was made for playing them. Commenting upon this situation, one of our issues of that period stated:

"Pious persons of wealth, knowing of no other lasting gift to make their favorite church, have bequeathed or presented chimes, leaving the ringing of them to the church itself. We know of one case where there are 44 bells and no music has been obtained from them, although they have been in place many years. The ringing of chimes is a work, however, that is never wholly abandoned by church trustees. Consequently some of the churches have erected crude appliances that ring the bells in a more or less satisfactory manner."

A committee from St. Patrick's examined the various methods that were being used elsewhere and didn't like any of them. As a result, it inquired, through COMPRESSED AIR MAGAZINE, for "the services of some compressed air genius who can devise a practical compressed air apparatus for ringing chime bells." The committee promised to lend assistance in conducting experiments with any systems that might be brought forward.

Several schemes were advanced and investigated, and one submitted by Hertford C. Champ of New York was adopted. It provided means for sending electrical impulses from the keyboard to the bells to open and close valves controlling air-actuated strikers. In a sub-basement of the cathedral rectory was set up an Ingersoll-Sergeant air compressor having a capacity of 69 cubic feet of air per minute at 80 pounds pressure. The air from this source was conveyed through 600 feet of 2-inch piping to a receiver in the belfry. From the receiver it passed through a 2-inch pipe that was run underneath the bells and had ¾-inch lines leading to the respective striking mechanisms. Each of these consisted of a cylinder having a piston connected with the bell clapper.

The keyboard for playing the chimes was in the sacristy of the church, there being a key for each bell. Pressure on a key transmitted electric current to the associate bell and opened a valve admitting air to the cylinder. This was said to be the first instance of chime ringing by air power, a method that has since then been generally accepted.

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FROM A BYGONE ERA

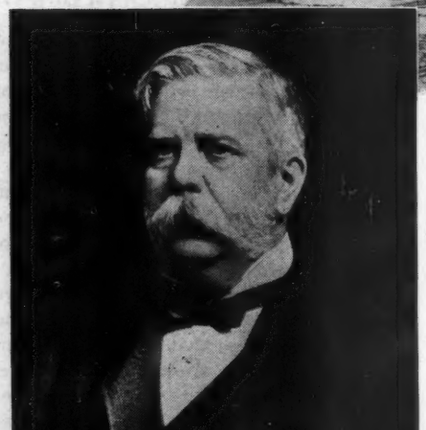
Above is shown the first compressed-air street car that was run by the Second Avenue Railroad in New York in 1879. The towering 4-stage compressor (right) that supplied later cars in New York with high-pressure air was afterward used by Prof. Charles E. Tripler in his experiments with the liquefaction of air. An air-operated automobile that was on the streets in 1900 is seen at the top. Pictured at the upper-left is the London underground passenger tube that was built in 1863 and abandoned ten years later.

Compressed-Air Cavalcade

THE president of the Newcomen Society, S. B. Hamilton, in addressing that leading British engineering group on October 10, 1945, said: "An idea born out of its time falls on stony ground and remains unfruitful. Heron and Ctesibius constructed many mechanical devices which could have been enlarged and used to develop mechanical power, but they remained curious toys. Where only slaves felt the pangs of physical toil, those who admired Heron's ingenious models did not think of developing them into prime movers."

Several of those ancient playthings were pneumatic contrivances which are described in the next article. There was no incentive to make them do useful work, and there were no skilled craftsmen to convert and improve them. More than seventeen centuries elapsed before men of the stamp of Galileo, von Guericke, Boyle, Bacon, and Torricelli began to delve into the realm of science, enunciate natural laws, and propound fundamental theories. They paved the way for Savery, Newcomen, Watt, Papin, Huygens, and others whose inventions inaugurated the mechanical age.

Denis Papin, French physicist (1647-1712), is reported to have been the first serious promoter of the use of pneumatic power. He conceived the idea of conveying parcels through tubes with suction and left some models, but he never actually tried out the schemes he proposed.



GEORGE WESTINGHOUSE

His air brake was one of the greatest influences in the promotion of compressed-air power. The centenary of his birth is being observed this year.

During the next 100 years many men attempted, without much success, to develop pneumatic-power systems of one sort or another. Here and there they were applied locally, but they did not come into general use, though those cumulative efforts undoubtedly eased the way for the later and more practical inventors.

Among those early-day isolated instances was that of harnessing air power for the operation of "water elevators" or pumps in the mines of Chemnitz, Hungary. Also, for centuries past man had been smelting ores of iron and other metals with the aid of air blasts from bellows and other primitive forms of blowers, and as the iron-making industry grew more important it was only natural that he should try to provide central air-compressing plants and to pipe the "pressurized" air to the furnaces. Before 1800 a Welsh engineer, whose name has not been recorded, is reported to have made an apparatus that utilized water power to compress air that was conveyed half a mile to blow a blast furnace and to operate machinery. However, the resultant

Significant Dates in the History of Compressed Air

1650– Otto von Guericke invented the air pump.
1660– Robert Boyle discovered fundamental laws governing gas compression.
1688– Denis Papin suggested using vacuum for pneumatic tubes.
1753– Hall pumped water with an air engine.
1788– John Smeaton invented a pump for divers.
1810– George Medhurst suggested pressure-tube transmission and built a compressor.
1830– Sir Thomas Cochrane patented the air lock.
1845– Triger conveyed compressed air 750 feet at a French colliery.
1849– J. J. Couch invented a steam rock drill.
1851– J. W. Fowle invented the first percussion rock drill.
1851– William Cubitt used air pressure in a caisson at Rochester Bridge, England.
1861– First use of air drills at Mont Cenis Tunnel by Sommeiller.
1866– Charles Burleigh air drills first used in an American tunnel (Hoosac).
1869– George Westinghouse patented the air brake.
1871– Simon Ingersoll introduced the universal tripod drill mounting.
1884– Henry C. Sergeant patented a hammer drill.
1886– First use of compressed air in shield tunneling.
1886– Dr. Julius G. Pohle invented the air lift.
1890– C. H. Shaw introduced the hammer drill (stoper).
1897– J. George Leyner patented hammer drills with hollow steel.
1889– E. W. Moir introduced the hospital decompression lock.
1912– Jackhamer drill was introduced.

blast was too feeble to be of much service.

In 1810, George Medhurst, in England, patented a method for sending parcels through pneumatic tubes, but it was apparently never put to use. His idea was revived by Vallance in 1824, but the result still was impractical. These and other efforts stimulated the persistent interest in pneumatic power, as is indicated by the fact that the Italian Government, in 1837, ordered that experiments be conducted to establish the laws that govern air transmission. Finally, in 1853, a workable pneumatic-tube system, which will be described later, was built in London.

Meanwhile, in 1845, a Doctor Gorrie of New Orleans, La., had developed the first practical mechanical refrigeration system to make ice for his own professional needs. He compressed air to 15 pounds pressure in one cylinder, then conveyed it to another in which it expanded and did work, hence became cold. Into the latter cylinder he injected brine to be cooled by the air, and subsequently used the brine to make ice by extracting heat from water. Although other gases have been substituted for air in the usual refrigeration cycle, it is pertinent to note in passing that this early apparatus exemplified the principle involved. Compressors are essential equipment in most refrigeration systems which, in turn, are an integral part of modern air-conditioning plants. The Gorrie method remained in favor for some years, especially in a number of our western cities. As late as 1894, St. Louis was considering piping cold air through the streets to serve businesses and residents, a survey of a section of the commercial district having shown that it was expending $172,000 annually for ice, which was selling at $4 a ton.

Two developments, spaced eight years apart, turned the public mind definitely towards the far-reaching possibilities of air power. The first of these was Sommeiller's application of compressed air in 1861 in the Mont Cenis Tunnel in the Alps, and the second one was the invention of the railroad air brake by George Westinghouse in 1869. The rock drills that had been conceived by Couch, Fowle, and others from 1849 on made the Mont Cenis Tunnel possible, but those machines had been designed to operate with steam, and it therefore devolved upon Sommeiller to devise means for compressing air for his drills and delivering it to them at their distant working places. How he accomplished these things is told in articles that follow.

Other men before Westinghouse had invented air brakes, but they were not practical. He was trying to work his brake with steam when he chanced to read of the transmission of compressed air at Mont Cenis and was thus started on the path that led to success. The public was loathe to accept the air brake, and called the idea of stopping trains with "wind" a ridiculous one, but Westinghouse had the courage of his convictions and persisted until he had overcome the numerous difficulties and established his invention as one of the leading mechanical devices of all time.

The old adage that necessity is the mother of invention perhaps explains the arrival of the rock drill at a time when it was sorely needed. In 1846 there began a period of expansion in the United States. The discovery of gold in the West and the colonization movement resulted in great shifts in population. Mining, railroad and highway building, quarrying, and other major enterprises that accompanied the westward trek were all fruitful fields of application for mechanical drilling. Rock drills were turned out in great numbers to meet the requirements, and the manufacture of compressors was stimulated as a natural consequence.

Then came an era of vast industrial growth. Between 1860 and 1900 the nation's population increased from 31,400,000 to 76,000,000. Great cities began to take form: The mode of living changed as people began to make less and buy more of what they consumed. Mechanical inventions laid the foundation for the expansion of industry, and more and more power was demanded as factories sprang up. This was the beginning of the age of electricity, but air power also was striding forward. Established uses multiplied, and new ones were conceived. To meet the needs of industry, pneumatic tools were devised and served not only to increase the productivity of labor but also to lessen human fatigue. Railroad shops were the first to adopt them, followed by foundries and then by virtually every branch of manufacture.

In 1894, Addison C. Rand, a pioneer maker of air-powered machinery, wrote: "Air, the simplest and most abundant

This Issue

WE are observing our fiftieth anniversary by devoting this entire issue to historical material. A conscientious effort has been made to be accurate, but time has a way of obscuring facts and it is difficult in most cases to check old records and statements. If any errors are noted, we would appreciate their being brought to our attention.

PNEUMATIC DRESS MODEL

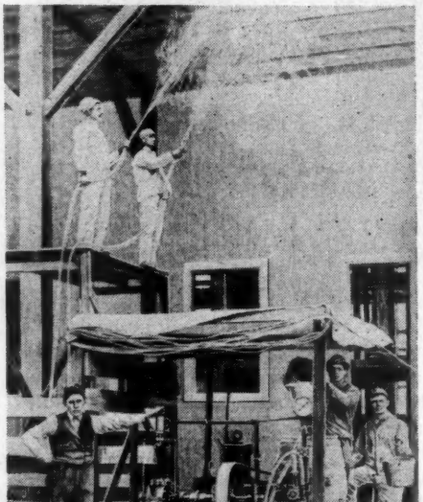
This appliance was considered a boon to seamstresses in the nineties and also was appreciated by husbands who had been pressed into service as trying-on dummies. It was invented by Ella M. Shrader of Seattle, Wash.

element (*sic*), has become a powerful factor in the arts, sciences, and manufactures. Its employment as an agent in the transfer of power is attended with absolute safety and certainty." Great tunnels had been driven both here and abroad, including a 7250-foot one at Niagara Falls that was completed in six months. Hell Gate in New York Harbor had been cleared. Brooklyn Bridge, with towers resting on piers that had been seated on rock with the aid of pneumatic caissons, had been opened in 1883. Men were envisioning deep transportation tunnels in cities, and as proof that passengers could be lowered and raised at stations were citing the success of the Eldorado Station of the North Hudson County Railroad near Weehawken, N.J., where "one elevator has carried 160 passengers, making the up trip of 153 feet in 40 seconds and the down trip in 35 seconds."

The mounting output of silver was attributed to the introduction of the rock drill, and it was noted that within the preceding three years some 300 machines had been put in service in the gold mines of South Africa where production was running at the rate of $2,000,000 a month. The most familiar uses of compressed air, so far as the general public was concerned, were those in connection with the air brake and the inflation of bicycle tires. Other applications included pumping water from wells by the air-lift method that had been invented by Dr. Julius Pohle in 1886, atomizing crude oil for firing boilers and forges, seasoning wood, driving locomotives in mines, and operating coal-mining machinery. Compressors were forcing natural gas through pipe lines up to 100 miles long. E. P. Lord, superintendent of H. K. Porter & Company, Pittsburgh manufacturers of compressed-air locomotives, stated in a talk to the Coal Operators' Association: "There are not less than 200 distinct and established uses of compressed air." The importance of compressed air being such as to warrant a publication devoted to its interests, COMPRESSED AIR MAGAZINE was established in 1896.

In 1900, a $35,000,000 contract was awarded to John B. McDonald for building New York's first subway which, for nearly 20 miles of its length, was to penetrate solid rock. McDonald and his financial backer, August Belmont, undertook the task in the face of predictions that they would never complete it. Yet, the line was opened in 1904, and the rock drill was credited with having speeded its construction. There had been bitter opposition to underground railways, and Russell Sage had declared that "New York people will never go into a hole to ride. It's preposterous"! Only four years before McDonald started the work, a New York court had refused to approve a subway project in a decision that began with these words from St. Luke: "For which of you, intending to build a tower, sitteth down first and counteth the cost, whether he shall have sufficient to finish it," and had further commented: "The probabilities indicate that after sinking $51,000,000 in it without being able to complete it, the enterprise would have to be abandoned . . . All that beheld it would begin to mock, saying, 'This city began to build and was not able to finish.' " By 1925, more than $600,000,000 had been spent on Gotham's rapid-transit network, and the investment is now well over the billion-dollar mark.

While on the subject of New York City, reference should be made to its towering skyscrapers and other huge structures whose roots were planted deep with the help of compressed air. In the water-bearing ground of lower Manhattan Island most foundations were sunk with pneumatic caissons, and nowhere else in the world has this art been developed to a higher state. Caissons were first used there about 1890 for the 18-story Manhattan Life Insurance Building on lower Broadway. The skyscraper era started some 20 years later, and engaged the attention of numerous foundation specialists such as John F. O'Rourke; the Foundation Company; Underpinning & Founda-



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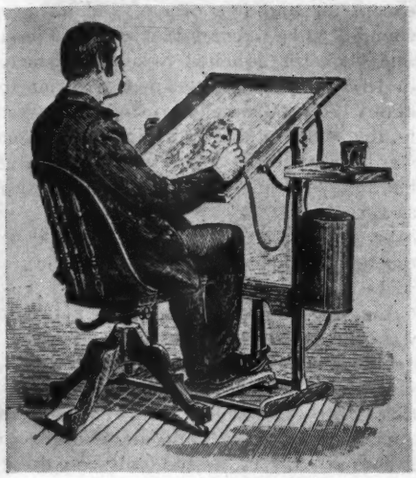
ORIGIN OF PAINT SPRAY

Spray painting is said to have been invented during the construction of the buildings for the World's Columbian Exposition that opened in Chicago on October 21, 1892. Frank D. Millet, a leading artist of that period, had charge of the artwork in connection with the fair. When the matter of painting came up, it was found that there was not time enough to do it in the regular way. To solve the problem, either Millet or his assistant, C. Y. Turner, built a machine to do the job. A piece of gas pipe, pounded flat at one end, served as a nozzle, to which air and paint were pumped through hoses extending from the barrel of paint. The air was supplied by an electric-driven compressor. It is reported that this apparatus "worked like a charm," and the work was completed on time, the Manufacturers Building, with 31 acres of floor space, being finished in a month.

PNEUMATIC LETTER PRESS WELCOMED IN OFFICES

BEFORE carbon paper came into use, business letters were written or typed with copying ink and file copies were made in a letter press. A sheet of tissue paper was laid on the original, a moistened cloth spread on top of both, and the three, together with similar sets, were placed in the press, the top of which was then turned down tight with a hand wheel. The pressure thus exerted effected the transfer. Oftentimes books of suitable paper were made up and the letters copied into them. In 1903 somebody invented a pneumatic press. One of the first units was put in service by the Big Four Railroad and was described as follows in one of our 1903 issues: "Those presses are surely the materilization of the dreams of a lazy man. All that is necessary is to place the copying book in the press, turn the handle of a stop-cock and the bottom of the press rises leisurely and squeezes that book like no other power on earth could. The mechanism is simple, just an air cylinder beneath the press, equipped with a close-fitting piston, which rises when air is admitted to the cylinder."



ARTIST'S AIR BRUSH

This small appliance, which was an offshoot of the larger paint-spray outfits, was introduced around 1895. As shown, the artist compressed his own air by foot power.

tion Company; Halbrook, Cabot & Rollins; and Arthur McMullen. The Municipal Building caissons extended 140 feet below the curb. The outer walls of some large structures, including the Equitable Building and the New York Stock Exchange, were reared on caissons that were sunk close together and then joined to enclose each site.

Farther uptown, rock exists at or near the surface, and compressed air comes into play in drilling excavations. Two large-scale rock-removal jobs were involved in the construction during the first decade of this century of the city's two railroad terminals, the Pennsylvania and Grand Central stations. As principal contractor, the New York Contracting & Trucking Company broke ground at the 28-acre Pennsylvania Station site on July 9, 1904. Eighty rock drills were in service there, and 140 teams hauled the spoils out of the pit to cars that transported it to 50 scows used in moving it to disposal areas. More than 3,000,000 cubic yards of material was handled. At the boundaries of the pit, vertical, unbroken walls were made by line drilling on 5-inch centers. In excess of 650,000 linear feet of drill holes were required for this phase of the work. The largest single building-excavation job in New York was carried out in the 1930's in connection with the erection of the various edifices comprising Radio City.

Space will not permit us to bring this account of the applications of compressed air up to the present time. We have said nothing about such things as W. W. Wotherspoon's system of dividing ships' holds into pressure compartments to aid in salvage operations; of M. U. Schoop's development of the method of metallizing; of the numerous uses of compressed air aboard ships and in launching torpedoes; of the conveying of concrete, grain, and other bulk materials by air; of air- and gas-lift pumping in oil fields; and of the wide employment of compressors in handling many kinds of gases in scores of different processes.

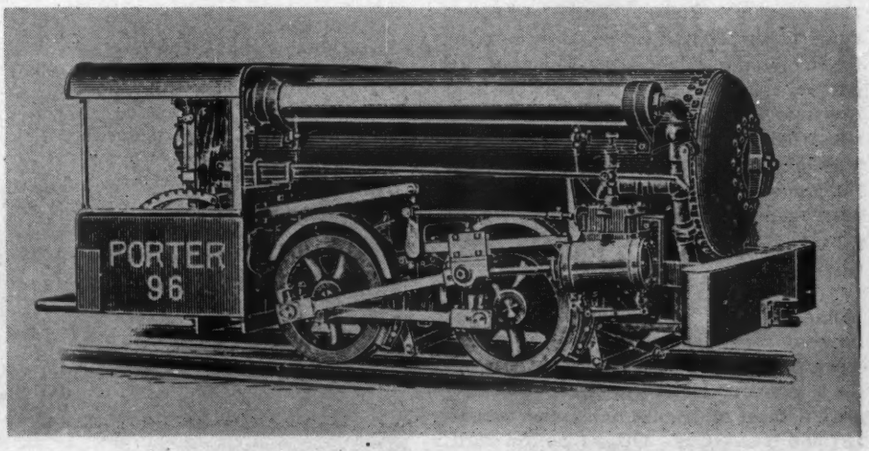
Gigantic construction undertakings such as the Panama Canal, and the great dams that have been reared in the western and southern sections of the country will be passed by with mere mention. Most of these topics have been covered in regular issues during recent years or months and are familiar to the present generation of readers. The remainder of this article will consequently be devoted to some uses of compressed air that were prominent in the past. Certain of them still survive, others have been superseded by different power agencies. They are of interest because they are a part of the history we are setting down.

Reference was made earlier to the first practical pneumatic tube that was built in London in 1853. It was only 220 yards long and 1½ inches in diameter and was designed for carrying telegrams. It formed the nucleus of an extensive telegram-and-mail system. The success of moderate-sized tubes led to many attempts to convert them for passenger service, and there was a time in the United States when it was freely predicted that they would some day connect all our large cities. Short ones were actually built, the first one in London in 1863. In section, it was shaped like the letter "D" laid on its left side and having rails at the corners. It was 4½ feet wide and 4 feet high and had cars that fitted the walls within an inch and carried a flap of rubber to close the intervening space.

Suction for propulsion was induced by a huge wheel. It had V-shaped cavities around the rim and was revolved at high speed in front of the bell-shaped opening at the tube terminal. There was too much leakage of air, even though the wheel was eventually increased to six times its original size. Despite the fact that the system cost $1,000,000, it was abandoned after intermittent operation, and it dropped from public notice until 1895 when it was discovered by an exploring engineer. The Beach pneumatic railway under Broadway, New York, which is described elsewhere in this issue, was opened to the public in 1870 and many notables rode in it but would not give it their financial backing.

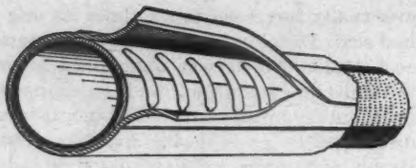
Extensive tube systems for carrying mails were constructed in many cities in Europe and the United States and are still widely used. Most of our early networks were designed by B. C. Bacheller, who was styled "the Edison of pneumatic sciences." The first one was built in 1893 in Philadelphia and was inaugurated by John Wanamaker, then postmaster-general.

Through the years there has been remarkably little serious conflict and controversy between compressed air and electricity. Both have their respective fields of service for which they are best qualified and are, for the most part, complementary rather than competitive. Compressed air had the advantage in that it was the first to be established in industry, and it was naturally put to some uses for which electric power was later substituted. One such instance was the operation of street cars. In the era of horse-drawn vehicles cities were faced with difficult transit problems. Street railways originally consisted of horse cars and cable cars, in that order, but neither one met the needs. The development of electric energy was in its infancy. Compressed air, on the other hand, was a somewhat familiar and trusted form of power, and its advocates, with understandable enthusiasm, sought to apply it to the traction field.



COMPRESSED-AIR LOCOMOTIVE

Units of this type were used extensively in mines and some are still in operation. They also served around powder plants, lumber yards, and in other places where sparks from steam locomotives constituted a fire hazard. Smith & Porter, later H. K. Porter & Company, began making them in Pittsburgh, Pa., in 1866. They were charged with air at pressures ranging from 500 to 2000 pounds, the higher pressures being required in mines where narrow passageways or sharp curves necessitated the use of units of small size to insure clearance.



1894 BICYCLE TIRE

Robert Thomson patented his "aerial wheel" in England in 1845. It was ahead of its time and was used little until bicycles became popular in the United States around 1885. Pneumatic tires were first applied to automobiles in 1892. Early tires had an inside rubber tube covered with leather to protect it from cuts.

The earliest and most successful of these transportation systems appeared in Europe, the first one being installed at Nantes, a suburb of Paris, by M. L. Mekarski in 1876. The air was compressed to 420 pounds, stored in bottles under each car, and fed to piston-type engines at reduced pressure. But just before that was done the air was heated to expand it so as to eliminate freezing in the engines and also to get more work out of it. A car would run 7.65 miles on the level before requiring recharging. Two such vehicles were exhibited at the Paris Exposition of 1878. They had seventeen seats, standing room for thirteen passengers, and weighed 8 tons loaded. The trackage was soon afterward extended to Paris and attained a length of 58 miles by 1900. Pressures were increased to as much as 1120 pounds, which lessened the frequency of charging. Mekarski and Victor Popp were both prominent in the Paris project, and in that city the General Omnibus Company built a plant housing 7000 horsepower of 3-stage compressors and laid pipes to charging stations along the routes.

The successes in Paris, Berne, Switzerland, and elsewhere abroad led to the promotion of compressed-air traction in this country. Robert Hardie, who had come to the United States after working for the builders of the Scott-Moncrief "air car" in Glasgow, Scotland, was the first inventor in the field, and his air engine was tried out on the Second Avenue Railway in New York in 1879. The Hoadley-Knight engine appeared later on, so that there were two competing concerns on the ground. These were eventually consolidated under the name of Compressed Air Company. Cars were operated in Rome, N. Y., and Chicago, Ill., and numerous installations were made in New York from 1894 to 1899. One that served for a year on the 125th Street Line covered a total of 23,000 miles and carried 137,386 passengers. Others ran on 23rd, 24th, 28th, and 29th streets.

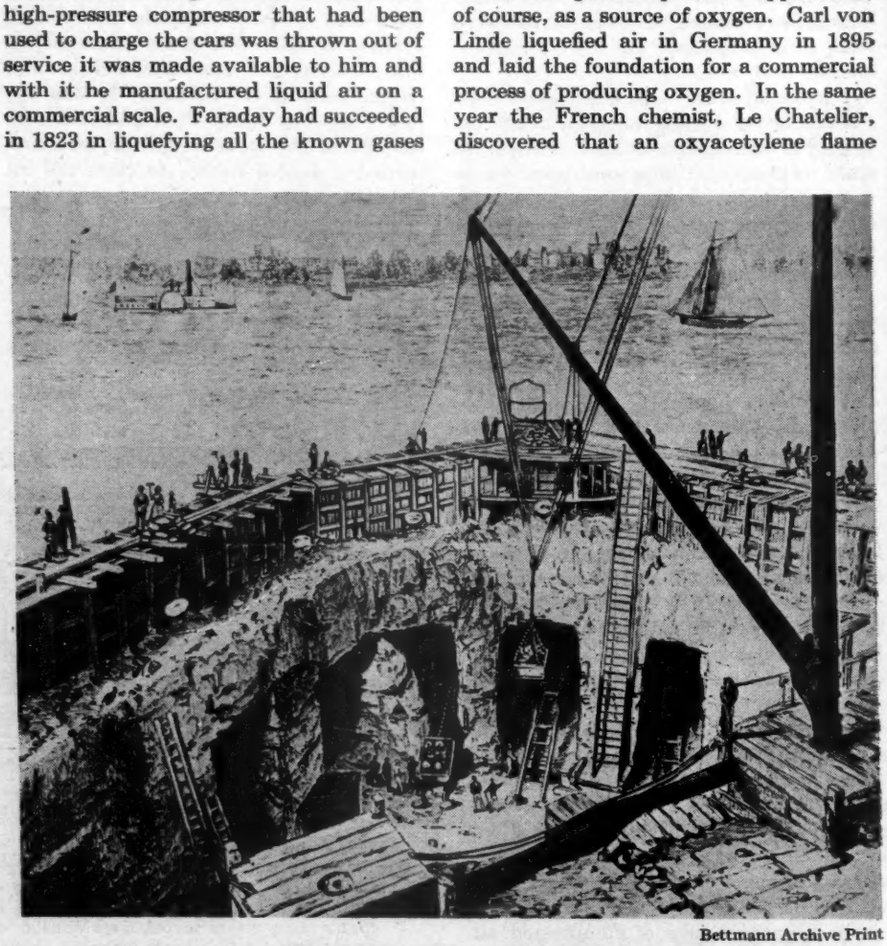
The importation of Mannesmann nickel-steel bottles from Germany permitted storing air at 1500 pounds pressure and increased the number of miles from each charge to 10 or 12. A 1500-hp., 4-stage compressor was set up to provide the high-pressure air. The daily newspapers gave considerable space to accounts of these enterprises, as public sentiment was against the electric trolley car, which then had many imperfections and was hazardous. There were references to "trolley-ridden Brooklyn," and one writer stated: "He who extirpates the trolley and gives us something that lessens the danger deserves a crown."

All this furore over pneumatic traction died down quietly when electric cars began to function properly. They were not only less expensive but simpler in construction, for there were 50 mechanical parts in one run by air, as against a motor and gear in the trolley. To illustrate how fast things change in this age, we record that, although less than half a century has passed since electric cars took over, they are now fast giving way to buses. According to a recent announcement, there will not be a trolley in New York City within a year or two.

The demise of the pneumatic street car in New York reacted to the benefit of one man. That was Prof. Charles E. Tripler, who had for some years been experimenting with liquid air. There are, in fact, some grounds for the opinion that he was the first to work out certain processes for which others were given credit. When the high-pressure compressor that had been used to charge the cars was thrown out of service it was made available to him and with it he manufactured liquid air on a commercial scale. Faraday had succeeded in 1823 in liquefying all the known gases except air and five others, and air was thought to be uncondensable until Pictet and Cailletet liquefied it simultaneously in 1877, but at great expense. Prior to about 1700 it was believed that the lowest temperature obtainable by artificial means was that induced by a mixture of snow and ice, and Fahrenheit used that temperature as zero on his scale. Then came the discovery that lower temperatures could be reached by expanding cooled and compressed gases.

Liquid air was a scientific toy before it was proved to be of great practical importance. One of the most popular vaudeville actors around 1905 was Joseph Yarrick, who performed many seemingly amazing feats with liquid air. Boiling as it does at -312°F., he suddenly converted hot puddings into frozen delicacies, made hammers of mercury that would drive nails, fashioned candles from kerosene, froze beefsteaks so that they gave out a metallic ring when struck, and rendered tin cans so brittle that he could shove a fist through their bottoms.

Great things were predicted for liquid air, ranging all the way from running automobiles to cooling mines with it and then operating rock drills with the compressed air obtained from it. In the end, it found its greatest practical application, of course, as a source of oxygen. Carl von Linde liquefied air in Germany in 1895 and laid the foundation for a commercial process of producing oxygen. In the same year the French chemist, Le Chatelier, discovered that an oxyacetylene flame



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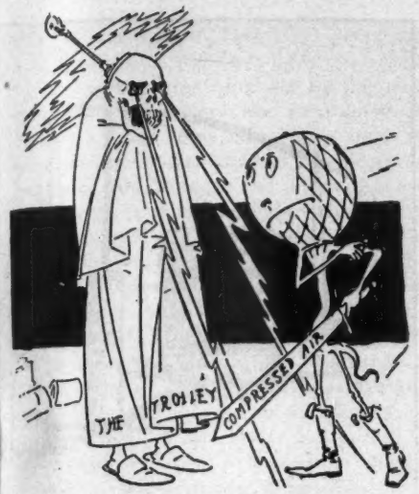
BUILDING HELL GATE BRIDGE

An 1887 print showing work underway on one of the pier foundations of the famous arch bridge across the East River, New York City.

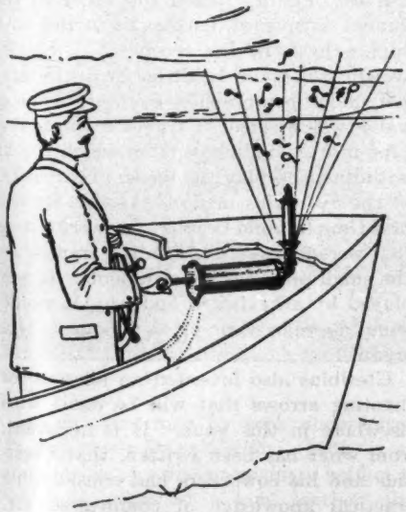


THE TROLLEY'S RIVAL

This cartoon, with the caption that is under it, was published in the "Chicago Times-Herald" in 1896. The trolley was pictured in the role of Death because electric cars had not at that time been developed to the point where they were safe. One source of information stated that the Brooklyn National League Baseball Club was nicknamed "Dodgers" because its players got their spring training by dodging trolley cars in Brooklyn.

would give a higher temperature than any gaseous mixture then known.

Three years previously, experiments at Spray, N. C., with the manufacture of aluminum in view, had revealed a method of making calcium carbide, the substance from which acetylene is generated. These several developments formed the basis of the welding industry, which made its initial momentous strides in Europe. The first commercial plant in the United States for the production of oxygen by the liquid-air process started operating in 1907. The oxygen was charged into cylinders under 250 pounds pressure, but the railroads refused for a time to transport them, maintaining that they were dangerous.



PNEUMATIC YACHT WHISTLE

This mariner's aid gave forth dulcet tones before the era of the raucous automobile horn. Compressed air also operated most of the warning signals of early-day lighthouses.

Before it had been demonstrated that electricity could be conducted long distances, the general transmission of air power was looked upon with favor. In Vienna, Birmingham (England), and especially in Paris, compressed-air distribution systems served successfully and were the inspiration for various potential projects in this country. However, they were nipped in the bud by the rapid advance in electrical engineering. When the first Niagara Falls hydroelectric station was being planned, the inclusion of a 5000-cfm. compressed-air plant was given consideration. It was backed for a time by George Westinghouse, and plans were actually prepared by Lupton & Sturgeon of Leeds, England.

The Paris air system was started in 1879 when two 6-hp. steam-driven compressors were set up in the basement of a residence and the air was delivered through a 3-mile pipe line for the operation of pneumatic street clocks. A master clock sent out an impulse to each connected timepiece every 60 seconds. The scheme worked so well that other clocks in public buildings and residences were incorporated in the system, and the air was gradually put to other uses such as running sewing machines in homes, various types of machinery in small factories, dynamos for electric lights, and for pumping beer in cafes.

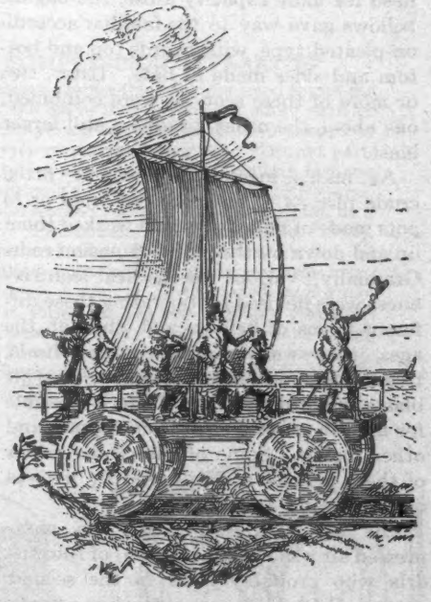
By 1883 the network had attained such proportions that M. Popp laid out a 24,000-hp. compressor station consisting of three 8000-hp. units. Only the first one was ever built, but it was characterized in 1898 as "the most important central power plant not only in Paris, but in the whole world." At that time the main distribution conduit was 138 miles long and laid entirely in underground tunnels. Forty-one miles served pneumatic clocks, of which the company owned 7500, and 97 miles supplied power for other purposes. Twenty miles of branch lines conveyed compressed air to 935 power consumers and to timepieces in 1637 establishments. Pneumatic power was operating engines totaling 1600 hp. and 180 passenger and freight elevators, as well as performing 163 additional jobs.

The four 2000-hp. compressors in the central plant were set up in line with their shafts connected by clutch couplings that permitted them to act in unison. They were vertical machines with the steam cylinders directly below the air cylinders. Each stood 40 feet high and weighed 1,000,000 pounds. The air was discharged at 120 pounds pressure and fed into a 20-inch main. At the places of consumption it was heated in small charcoal-fired units (M. Popp was credited with having originated reheaters) and passed through a meter before application. In many establishments where it did work in engines, the cold exhaust served as a refrigerant.

Another fleeting use of compressed air was that of running automobiles. The machines designed for that purpose were promoted by the same interests that built air engines for street cars. The first automatic starters for automobiles were air operated, and nearly all the leading makes of cars around 1912 were provided with them. The prevailing type injected air into the cylinders in the order of their firing, the air being supplied by a compressor driven by the motor. The Liberty airplane engine that powered many of our World War I aircraft was air-started.

The pneumatic system gave way to the present type because it was not compact enough to fit into the limited space available in an automobile. It was, however, retained for a long time on heavy vehicles, and a starter of the same sort is still employed for stationary gas and diesel engines. The pneumatic tire is of course essential to the automobile and probably represents the use of compressed air that is most familiar to the general public. Invented in 1845, inflatable tires served to a limited extent on carriages and were first made for motor cars by Michelin & Company in France in 1892.

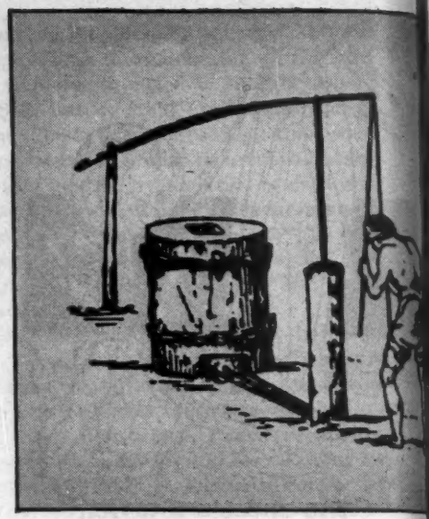
Another early use of compressed air in motor cars was that of cushioning the springs with shock absorbers. This is now done hydraulically. George Westinghouse and Joseph Hofmann, the concert pianist, were inventors of successful types of these "air springs."



SAIL CAR OF 1829

This form of air power was tried out on some of the early railroads, but there were too many calm days to make it successful. Sail cars are still used in certain favorable areas of the world, one of which is Chile.

Development of the Compressor



THE first air compressor was formed when some primitive man belled his cheeks and blew upon the sparks of his fire to excite flames. Man next blew through a reed, then through a hollow pipe. The first inanimate compressor was a crude bellows, probably fashioned from goatskin sewed to form a sack. There is a representation of a bellows painted on a wall of the tomb of Rekhmara, governor of Thebes and vizier to Thothmes III, who was King of Egypt in the time of Moses. There are references to bellows in the Old Testament. Jeremiah recorded that "The bellows are burned, the lead is consumed of the fire"; and Ezekial referred to the gathering of "silver and brass, and iron, and lead, and tin in the midst of the furnace to blow the fire upon it to melt it."

The first improvement in bellows was the addition of a crude valve consisting of a leather flap opening inward. This alternately uncovered and covered an air inlet as the top of the bag was pulled upward to inflate it and then flattened to expel its contents through some sort of a hollow connection leading to the fire. As need for more capacity arose, the baglike bellows gave way to the familiar accordion-pleated type, with boards top and bottom and sides made of hide. Later, two or more of these sections were combined, one above the other, to give a still larger blast.

As man's ingenuity grew, he fitted crude pistons to hollowed-out trees or to pots made of baked clay and worked them up and down by the aid of extension rods. Gradually, various mechanical contrivances were devised for operating these different forms of bellows and, through the ages, they were run by water wheels, treadmills, and other means. The air blasts induced by them made it possible for man to smelt ores of iron, copper, and other metals. Some of the cruder forms of these bellows are still used by natives of Africa and India.

The earliest-known writer on compressed air was Hero (or Heron) of Alexandria who probably lived in the second century B.C. He wrote a 2-volume work, *Pneumatica*, which described various applications of air pressure and vacuum. Hero was a Greek geometer who left his home to study under Ctesibius, one of the learned men of the period. The two later worked together, and perhaps jointly developed some of the things of which Hero wrote. Many of them were made for pagan priests to enable them to exhibit their supposedly supernatural powers and thereby impress the superstitious people.

Among those devices were a fountain, in which a jet of water was sustained by air pressure; coin-in-the-slot machines that siphoned drinks of wine from containers; a fire engine, and an apparatus for opening and closing temple doors. The latter made use of heat to expand air, a phenomenon that is exemplified by heating a corked bottle until the increased air pressure blows the cork out. A "sacred" fire kindled under a hollow altar caused the air within to expand and thus forced some of it through a tube into a spherical water-filled vessel placed in sight beneath the altar. The air pressure, in turn, drove some of the water out of the vessel into a bucket which acted as a counterpoise. It was connected by cables and pulleys to a pair of vertical posts to which the doors were attached and turned the posts in such a way as to open the doors. When the altar fire was quenched, the air would cool, the water would be drawn back out of the bucket, and the doors would close. As the movement of the air could not be seen, this demonstration was very mystifying to the ignorant watchers.

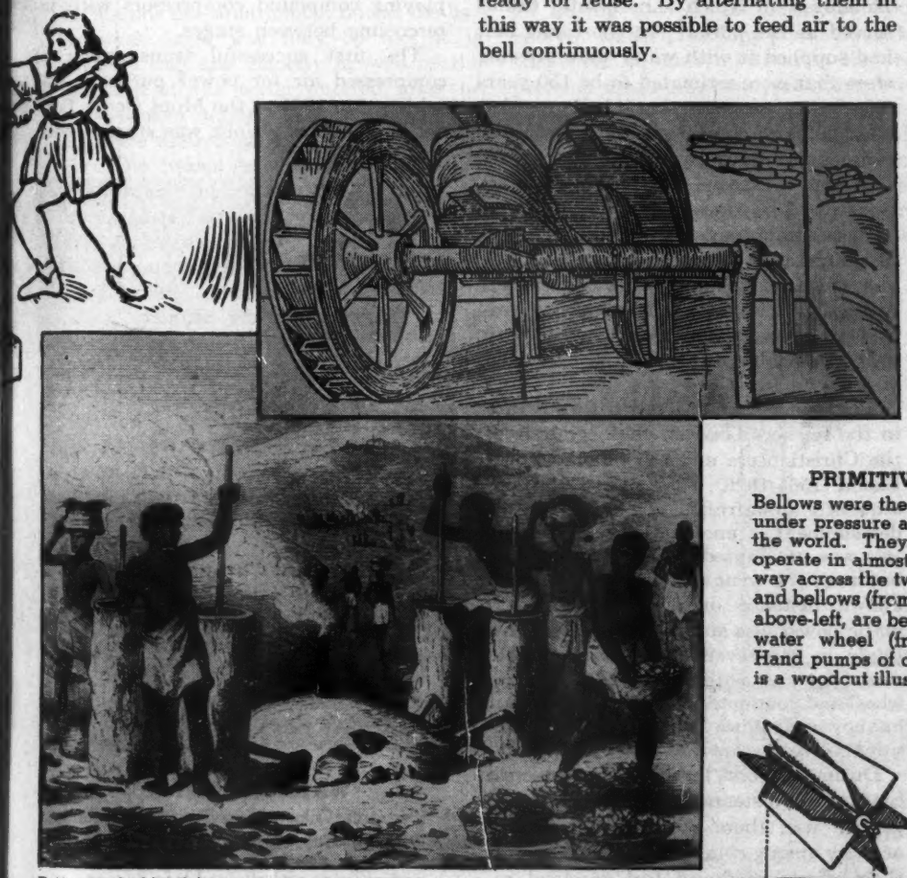
Of greater and longer-lasting significance than these perplexing pneumatic contrivances was a type of air-blown organ conceived by Ctesibius and described by Philon, another of his pupils. The earliest of these wind instruments was the *syrinx*, which undoubtedly dated back to the remote past. *Syrinx* is the Greek word for Panpipes, and its invention was ascribed to Pan, the Greek god of flocks and pastures. It consisted of vertical reeds, differing in number and length, with the open ends uppermost in a horizontal line and with the lower ends stopped by knots and gradually declining from right to left. Each reed gave out one note. The *syrinx* was originally played by mouth pressure, then by air from bellows. The instrument devised by Ctesibius was called a *hydraulus*, which Philon termed "the kind of syrinx that is played by hand."

The *hydraulus* had in its base an inverted funnel that was immersed in a tank of water and rested on short feet to hold it off the bottom. Air was pumped into the funnel by working two pumps, one on each side of the organ, constructed of bucket within bucket and fitted with valves. The air forced the water in the funnel downward, causing it to rise to a higher level in the receptacle. By its weight, the water held the air in the funnel under compression so that, when a valve was opened, it traveled through a pipe into a wind chest from which it was withdrawn to play the reeds. The nature of the *hydraulus* made it possible for the first time to build organs of powerful tone that were more suitable for the arena than the small pneumatic instruments. It was played by a keyboard and was, it would seem, a predecessor of the modern pipe organ.

Ctesibius also invented an air gun for shooting arrows that will be dealt with elsewhere in this issue. It is apparent, from what has been written, that Ctesibius and his coworkers had considerable practical knowledge of compressed air. Their compressors, which yielded only low pressures of course, were reportedly of the cylinder-and-piston type akin to the modern hand bicycle pump. They were probably made of bronze.

There is ample evidence that diving

was practiced more than 2000 years ago and that means were available even then for supplying breathing air to the men underwater. Divers are mentioned in Homer's *Iliad*, and they were used in military operations during the sieges of Syracuse and Tyre, in the latter instance by troops under Alexander the Great. Livy records that divers recovered considerable treasure from the sea during the reign of Perseus. The first mention of any appliance to assist divers was by Aristotle (384-322 B.C.), who wrote that they were sometimes provided with "instruments for drawing air from above the water and thus they were able to remain a long time under the sea." Alexander is reported to have made a descent in a machine called a *colimpha*, which made it possible for a man to keep dry and at the same time admitted light. Roger Bacon, too, is supposed to have invented a contrivance in



Bettmann Archive Print

1240 enabling men to work underwater. In Vegetius's *De re Militari* (1532) is an illustration of a diver wearing a helmet to which is attached a long leather pipe leading to the surface, where its open end is kept afloat by means of a bladder.

Working at Ramsgate Harbor, England, in 1788, John Smeaton, a British civil engineer, developed a pump to supply divers with air. In 1819, Augustus Siebe invented his "open" diving dress which was provided with air by a force pump. The suit had a metal helmet that rested on shoulder plates and was attached to a jacket made of waterproofed leather. Air was delivered through flexible tubing to an inlet valve on the helmet, and the pressure thus exerted kept the water level down below the diver's chin. The air escaped at the edge of the jacket, just as it does in the modern diving bell.

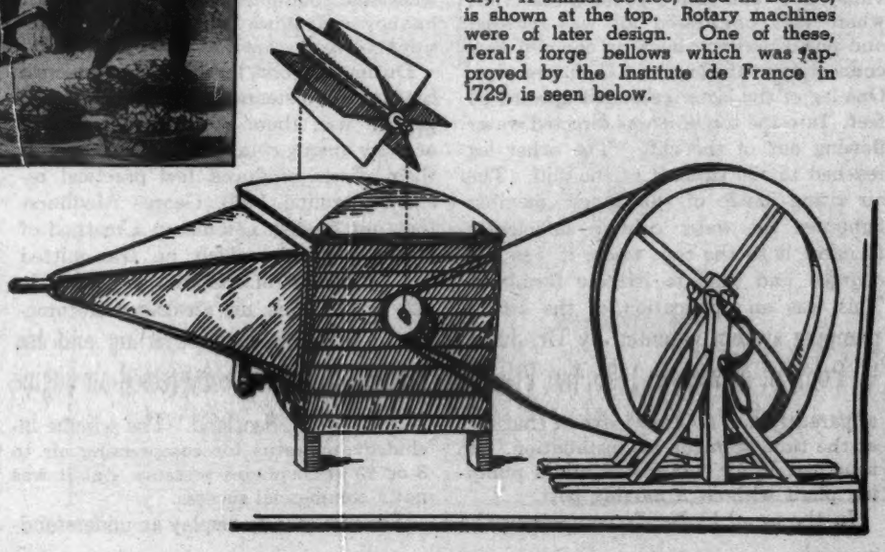
The first practical diving bell was invented in England by Dr. Edmund Halley, secretary of the Royal Society, and was described in the *Philosophical Transactions* for 1717. Two lead-lined barrels, each having a hole in the top and bottom heads, supplied it with air. To the topmost hole in each container was attached a leather hose. By pushing a barrel down into the water, the air within it was compressed and forced through the hose to the diving bell underwater. While one barrel was being lowered the other one was being raised and drained, making it ready for reuse. By alternating them in this way it was possible to feed air to the bell continuously.

An early type of air compressor that represents one of man's first successful efforts to make waterpower do his work was an apparatus that acted on the entrainment principle. It was mentioned by Pliny in his *Natural History* in the first century A.D., and is thought to have been old even then. In its original form it consisted of an inclined tube of bamboo into the upper end of which was led a stream of water that carried entrained air with it in its downward passage. Some of the air entered with the water, but most of it was drawn in through small holes bored in the side and near the top of the tube the lower end of which was inserted in a bag, probably made from the skin of some animal. The air, compressed by the weight of the water, escaped into the upper part of the bag, whence it was fed through a pipe or tuyere to a forge. The water flowed out through an opening in the bottom of the bag.

This apparatus was revived and improved upon in the thirteenth century by Spanish ironworkers on the slopes of the Pyrenees and served to supply their Catalan forges with blast air. It was called a *trompe* (French for trumpet), also a water bellows and a water blower. It is described in connection with an accompanying illustration. As utilized in Spain, this device is reported to have given a blast "of respectable volume" at a pressure of a pound or two per square inch. With it, a Catalan forge is said to have produced a ton of iron from 3 tons of hematite ore and 3 tons of charcoal. The *trompe* was the prototype of the blowing engines used later with iron blast furnaces.

PRIMITIVE COMPRESSION APPARATUS

Bellows were the earliest mechanical devices used to put air under pressure and still serve that purpose in many parts of the world. They have varied in type and been arranged to operate in almost every conceivable manner. Pictured partway across the two pages is a Lusitanian tin-melting furnace and bellows (from Agricola's "De re Metallica" of 1556); and, above-left, are bellows worked by cams on a shaft driven by a water wheel (from "Pirotechnia" of Biringuccio, 1540). Hand pumps of different kinds followed bellows. At the left is a woodcut illustrating a type serving an African iron foundry. A similar device, used in Borneo, is shown at the top. Rotary machines were of later design. One of these, Teral's forge bellows which was approved by the Institute de France in 1729, is seen below.



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CLEARING WOODEN CASKS

A wine dresser applying bellows to kegs "to chase out the foul air." From a woodcut in a treatise dealing with agricultural methods. It was published in 1507.

Hydraulic compressors, based on the principle of the *trompe* but built on a much larger scale to provide greater volumes of air at higher pressures, appeared both in America and in Europe in the latter part of the last century, and at least two of them in the United States are believed to be still in operation. The first one in this country was constructed in 1890 in the Snake River desert in Idaho by a man named Priestly. At the building site, water gushed out of a 300-foot cliff at a point 190 feet above the river.

The upper part of the cliff is a thick lava flow from the bottom of which the water issued along a plane that had once been a lake bed. Priestly constructed a pipe to conduct some of the water, together with entrained air, down to the valley floor and into a covered reservoir, where the compressed air was released and piped partway back up the cliff to a connection at the base of a U-shaped pipe. One leg of the latter extended upward 60 feet. Into the top of it was directed water flowing out of the cliff. The other leg reached to the summit of the cliff. The air rising inside of this longer member lightened the water column sufficiently to carry it to the top, where it was discharged and used to irrigate farmland. This was an application of the air-lift pumping system patented by Dr. Julius G. Pohle of Arizona in 1886, but Priestly apparently had no knowledge of that fact at the time he made his installation. He thus had an air compressor and a pumping plant without a moving part.

In the usual hydraulic compressor the water descends through one or more shafts, which have to be 230 feet deep to furnish air at 100 pounds pressure. There must also be an underground air chamber and means for carrying off the water. As all these features usually have to be excavated, the first cost of such a plant is high, but the operating costs are very moderate. The first American to experiment with high-pressure compressors of this type was J. P. Frizell of Boston who was granted patents in 1878. Other patentees were Adolf F. du Faur, Col. George E. Waring, and C. H. Taylor. The latter obtained patents in 1895 and built a number of the commercial plants on this continent. For that reason they are commonly known as Taylor hydraulic compressors.

Similar hydraulic plants, although smaller and for lower pressures, are known to have been constructed several centuries ago. In 1908 a mining man found the remains of one near Tegucigalpa, Honduras, in which a horizontal tunnel served as the outlet. In the canal that had supplied it with water were growing trees that were estimated to be 150 years old. Indications were that it had provided blast air for a copper smelter. Hydraulic compressors have two desirable features that were of especial advantage in the last century. The air is cooled by the water as it is compressed and, in addition, the discharge air, strangely enough, contains less moisture than the free air carried originally. The early builders of mechanical compressors had trouble with both heat and moisture, as will be explained later.

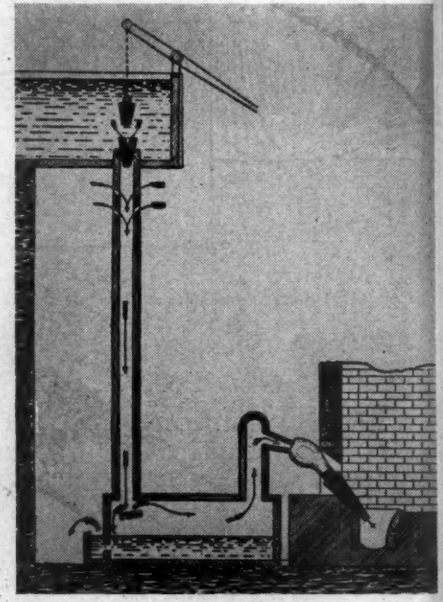
There was comparatively little advance in the sciences between the beginning of the Christian era and the time of Roger Bacon (1561-1626). This period was consequently an unfruitful one as regards the development of pneumatics. Some progress was undoubtedly made in this field, but most of it went unrecorded. The first known instance of transmitting pneumatic power was an installation by Denis Papin in the seventeenth century. He compressed air with energy from a water wheel and conducted it a considerable but unknown distance through tubes, presumably to do work of some sort.

During the first half of the nineteenth century, with steam engines in somewhat general use, there was a good deal of activity among compressor inventors, but their efforts produced few practical results. Around 1800, George Medhurst took out English patents on a method of compressing air which he transmitted for the purpose of operating engines. He also constructed an air-driven automobile. In 1816, James Sterling and his brother invented a compressed-air engine in Edinburgh, Scotland. The scheme included apparatus for compressing air to 8 or 10 atmospheres pressure, but it was not a commercial success.

The first man to display an understanding of air compression as it is practiced now was William Mann of England. In 1829, in applying for a patent on a compound compressor, he stated: "The condensing pumps used in compressing, I make of different capacities, according to the densities of the fluid to be compressed, those used to compress the higher densities being proportionately smaller than those previously used to compress it to the first or lower densities." Except that the important function of intercooling is omitted, this is an accurate description of the way in which multistage compression is effected today.

Others who advocated compound compression were Thilorier in France and Baron von Rathen in Germany. Thilorier was awarded a medal by the French Academy of Sciences in 1830 for his method of compressing gases in stages. In 1849, von Rathen suggested using compressed air at 750 pounds pressure for running locomotives. He advised employing compound compressors with intercooling between stages.

The first successful transmission of compressed air for power purposes was achieved in 1861 at the Mont Cenis Tunnel in the Alps. Work was started with



WATER "TROMPE"

Hydraulic blower used with Catalan forges. From an upper reservoir, providing a constant head of water, a vertical pipe or hollowed tree descended to a wooden blast box, usually about 30 feet below. Near the top of the pipe were holes for the admission of air. The water was directed into the top of the pipe by means of a funnel that could be closed by a plug, as shown. The falling water, carrying air it had drawn in through the holes, struck an inclined board, thus releasing the compressed air. The water overflowed the blast box and escaped, while the air was directed through tuyeres to the furnace hearth. A continuous blast was produced as long as the water flowed.

hand drilling in 1857, but progress was so slow that consideration was given to power-driven rock drills that had been invented in the United States and Europe. Up to that time, however, those machines had been operated only by steam, which was unsuitable for use in the confined spaces of a tunnel. As a solution of the problem, M. Sommeiller, a student of the University of Turin, suggested compressed air. He and two classmates, named Grattoni and Grandis, worked out a design for a water-driven compressor. Some of them were manufactured by Messrs. Cockerell near Liege, Belgium, and put in service at one end of the tunnel. When they proved to be successful, others were added. Eventually there were sixteen—ten at the one end and six at the other.

As shown in an accompanying sketch, the original Sommeiller compressor consisted of an inclined pipe that conveyed water to a vertical cylinder in which the water served as a piston. The air pressure obtained is reported to have been around 90 pounds per square inch, but as the hydrostatic head was only 85 feet it is evident that the velocity as well as the pressure of the water entered into the compressive action. Consequently, the machine was essentially a water ram. Before the tunnel was completed, another apparatus—the "improved" Sommeiller compressor—was put in service. It was a flywheel type of unit driven by a water wheel and having two horizontal cylinders in line, each connected with an upright cylinder containing water. The sweep of the pistons forced the water upward alternately into the vertical cylinders. The compression cylinders were equipped with intake and discharge air valves, as well as with valves that admitted water to compensate for that carried away in the air or lost through leakage.

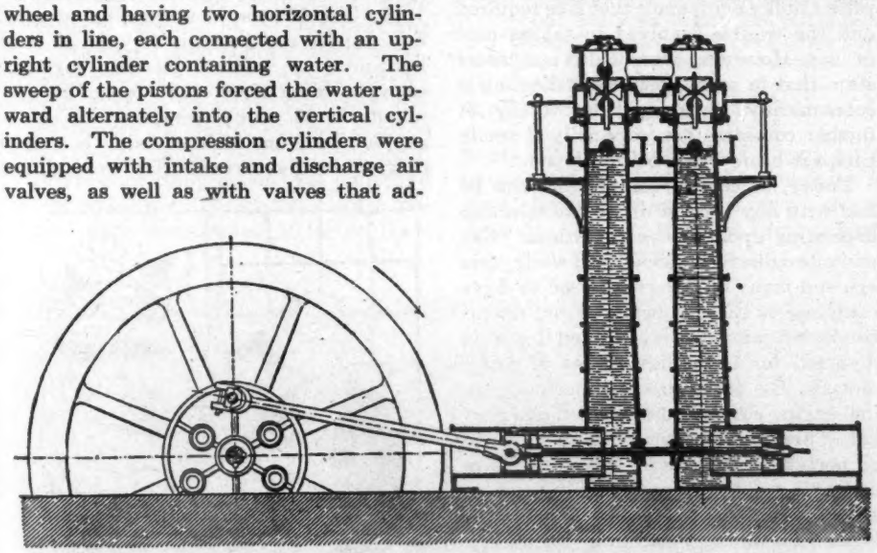
In 1866, Charles Burleigh built an air compressor to operate rock drills of his design in driving the Hoosac Tunnel in Massachusetts. This was probably the first American-made compressor of practical value and, perhaps, also the first to compress air by the direct action of a metal piston instead of by using water as an intermediate agency. In an effort to remove some of the heat of compression, water was sprayed into the cylinders. Although Burleigh is generally credited with designing this machine, it is likely that some of his associates, especially Thomas Doane, chief engineer on the tunnel project, had an important hand in it.

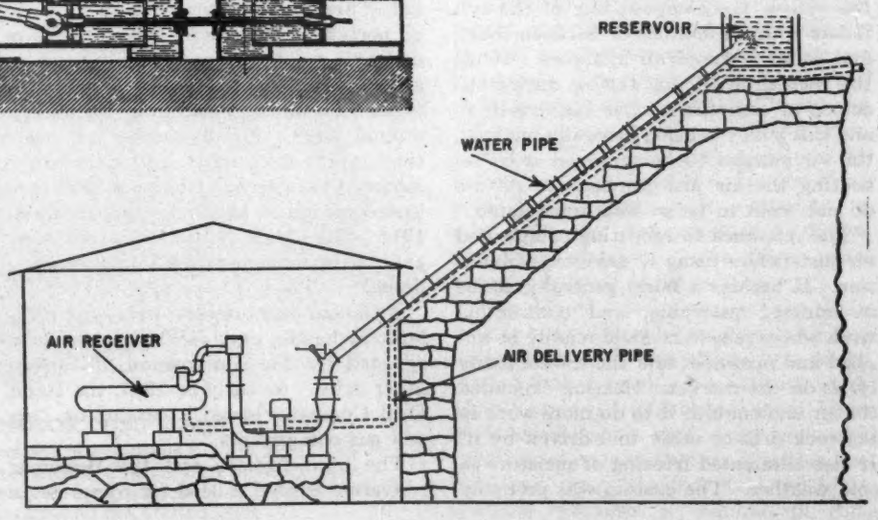
From that time on, development of the compressor was rapid, although there were still many difficulties to be surmounted. Single-stage compression prevailed for almost 25 years, and great trouble was experienced in cooling the air during the process, although Mann and von Rathen had long pointed out that this could be done by dividing the compression into stages and providing interstage cooling. Some designers reverted to the Sommeiller method of pushing water ahead of the piston, others resorted to spraying water into the cylinder, and still others circulated water through cylinder cooling jackets. Compressors thus came to be classed as either "wet" or "dry."

Throughout this period, Ebenezer Hill of Norwalk, Conn., who was described in an article published in 1898 as "our highest authority on compressed air," staunchly advocated compound compression. His contemporaries gave him the major share of the credit for its ultimate adoption. This movement had progressed so far by 1894 that Addison C. Rand, one of the pioneer compressor builders, wrote: "The air compressors now in general use are fitted for surface cooling, and deliver dry air. The method used is the result of long experiment and experience and practically eliminates the physical difficulty of extremely high temperatures of air attendant upon compression, which up to recent years has made the practical application of compressed air almost impossible."

Before leaving this subject, it should be mentioned that increased engineering knowledge acquired meanwhile has led to the designing of single-stage compressors for discharge pressures up to 100 pounds in which the air is adequately cooled for most commercial purposes. Also, it should not be forgotten that aftercoolers are now available to extract most of the heat of compression immediately after the air leaves the compressor. The definite economies and advantages of stage compression have, however, dictated that it be used predominantly for pressures above 50 pounds.

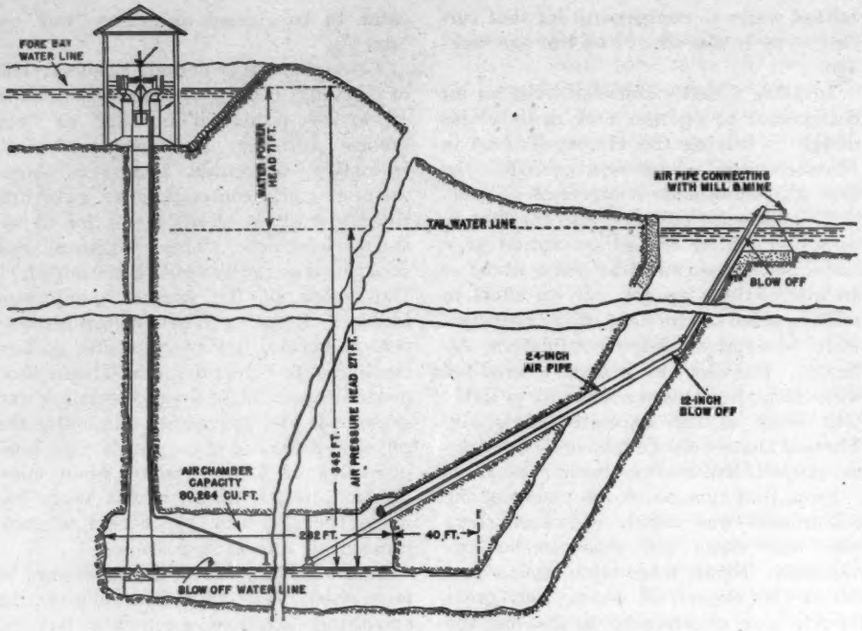
Until around 1900, most compressors were driven by steam engines, with waterpower serving in the relatively few places where it was available. Electric motors when first introduced operated compressors through belts or gears, while direct-connected units began to appear with the development of synchronous motors soon after 1900. But for a long time thereafter the favored drive for large-capacity compressors was the compound Corliss steam engine. The first electric units were used by power companies, or on electric cars for air-braking service.





SOMMEILLER'S COMPRESSORS

The original compressor at Mont Cenis Tunnel and the first one ever used in rock drilling is shown at the right. Water was allowed to flow through the inclined supply pipe, forcing air into the higher vertical column at the bottom and compressing it. Next a valve was closed to shut off the water, the air was admitted to the receiver, and the water drained out of the lower part of the apparatus. The cycle was then repeated. Sommeiller's "improved" compressor driven by a water wheel is pictured above. The air was compressed by columns of water rising alternately in the two vertical cylinders.



HYDRAULIC AIR COMPRESSOR

Sectional drawing of a hydraulic air compressor designed and built by C. H. Taylor of Montreal, Canada, at the Victoria Mine, near Rockland, Mich., in 1904. There are three concrete-lined water-intake shafts, each 330 feet deep and 5 feet in diameter. To obtain a sustained supply of water the Ontonagan River was dammed at a point 4000 feet upstream from the site. The compressor was designed to deliver 36,000 cubic feet of air per minute at 117 pounds pressure. It developed 5000 hp. and was constructed at a cost of $22 per horsepower.

The general status of the air compressor at that time is summarized in the following quotation from an editorial in COMPRESSED AIR MAGAZINE for November, 1902: "The attention of makers of air compressors is being attracted more and more to the possibilities of the electric-driven compressor . . . There was a time when the economical development of power in the air compressor was the least thought of subject during its construction. The competition of electricity and the general progress of the age have combined to change this viewpoint. The result is a wonderful improvement in the efficiency of compressed air machinery. Among the recent improvements . . . are those in the efficiency and durability of the valves, the compounding of the cylinders with an intercooler between them, and water-jacketed air cylinders. While the wisdom of cooling the air during the course of compression has been realized, and this policy is being generally pursued, the advantages to be obtained from reheating the air just previous to its use do not seem to be so well appreciated."

The reference to reheating compressed air just before using it deserves elaboration. It became a fairly general practice in mining, quarrying, and contracting work where reheaters could readily be applied and operated, and there were many types on the market. Heating expanded the air and enabled it to do more work in the rock drill or other tool driven by it. It also eliminated freezing of moisture in cold weather. The custom was probably abandoned because of the additional rather bulky equipment that was required and the trouble involved in taking care of it. However, present-day engineers state that in many instances reheating is economically sound and is worthy of further consideration, especially if small, compact heaters can be developed.

Today, of course, compressors can be had with any type of drive, the selection depending upon service conditions. Gas and oil engines entered oil-field work years ago and many of them were used to drive compressors through belts. Later, direct-connected compressors appeared that were designed for both these types of prime movers. By 1915 direct-connected gasoline-engine compressors were on the market. Their greatest service is in the field of portable compressors and in the form of small usually air-cooled units such as are employed in automobile service stations. Portables were first introduced around 1899. For a number of years they were essentially stationary units mounted on wheels. Compact, self- contained machines began to appear about 1914. Since then portables have undergone many refinements and much streamlining.

Although compressors were originally built to handle only air, they were soon adapted for the compression of various other gases. As early as 1904, the Rand Drill Company issued a catalog on "air and gas compressors."

The blast furnace and the Bessemer converter created a need for compressors delivering large volumes of air at low pressures. The first blast furnaces were blown with air from bellows operated initially by water wheels and later by steam engines. Bellows gave way to "blowing tubs," so named because the compressing cylinders were made of wooden staves and were put together in the manner of a barrel but with straight sides. The early furnaces used about 2 pounds air pressure, but as the modern type appeared, the pressure was gradually increased to the 15-30 pound range.

Converters, invented simultaneously by Sir Henry Bessemer in England and William Kelly in the United States, came into use just prior to 1860 and created a demand for compressors that would deliver air at a maximum pressure of 35 pounds. From the old blowing tubs evolved blowing engines, counterparts in metal. These were huge reciprocating compressors with cylinders having the necessary large discharge capacity. As blast furnaces and converters grew in size, the pistons of the blowing engines were gradually speeded up from 600 to 1000 feet per minute to maintain the great volumes of air essential to their operation.

To fill the need for a machine of reasonable size that could deliver a large amount of air, the centrifugal turboblower was developed. Its invention is attributed to Professor Rateau of France. It was manufactured in this country as early as 1905. The 500-ton blast furnaces of that day usually required the services of two horizontal or vertical blowing engines, each providing 25,000 cubic feet of air per minute at 25 pounds pressure. So as to supply the same volume with but one unit, the early turboblowers were given

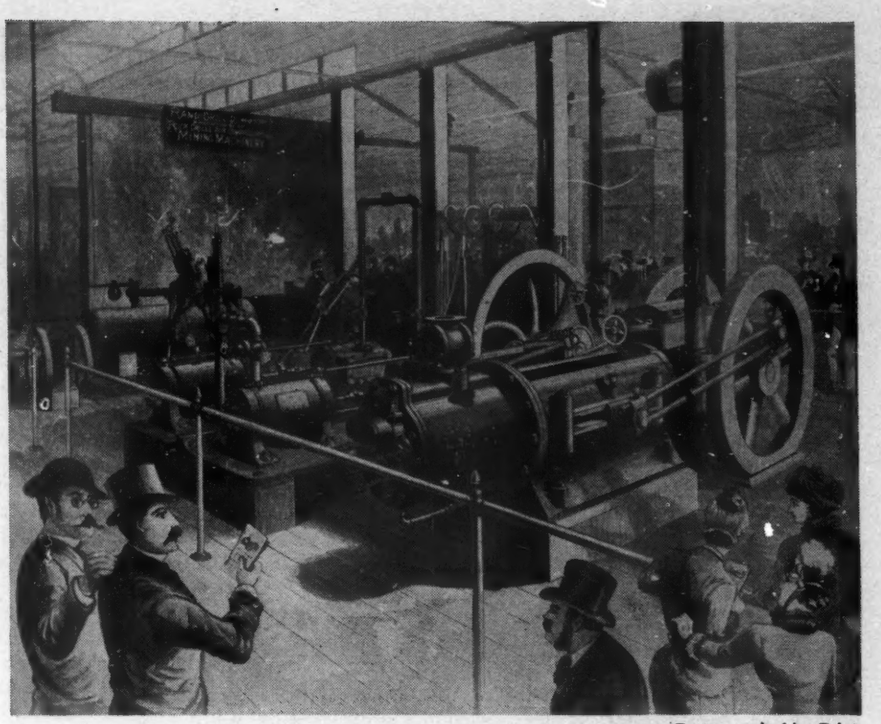
A popular belt compressor

(From our March, 1896, issue)

a capacity of 50,000 cfm. Since then it has been gradually increased, and machines that deliver 125,000 cfm. at 35 pounds pressure were built by Ingersoll-Rand Company during recent war years. Each is driven by a 14,000-hp. steam turbine.

Turboblowers now have many applications outside of the steel industry. They are used by public utilities for distributing gas; for agitating sewage in disposal plants; and for handling various gases in process industries, of which the manufacture of yeast is an example. Higher-pressure units, called turbocompressors, have been developed for service where unusually large volumes of air at pressures of around 100 pounds are required. They have been especially favored in the Witwatersrand gold-mining district of South Africa, and a few units have been put in operation in the United States. Smaller blowers of the rotating type for low-pressure service are to be found in many industries. Typical applications are: furnishing combustion air for oil- and gas-fired furnaces and melting iron in cupolas.

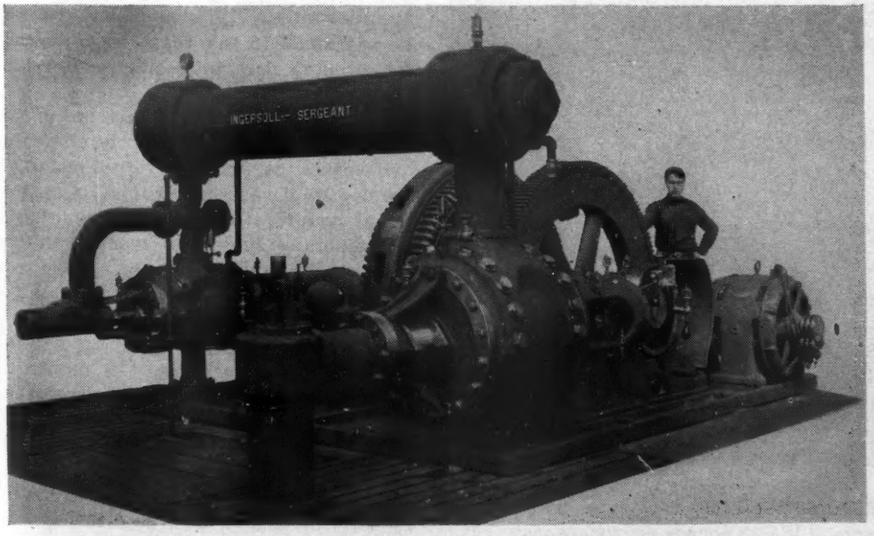
Until about 1895 there was little demand for compressed air at pressures higher than 100 pounds and, consequently, few compressors up to that time were built with more than two stages. Perhaps the earliest use of pressures above 100 pounds was in connection with air-operated street cars and locomotives which eventually operated on pressures ranging up to 1500 and 2000 pounds, respectively. The air was not actually fed to the driving motors at those pressures; the latter were used to store the desired volumes of air in reservoirs of limited size. A little later, high-pressure compression was employed in liquefying air. Three- and 4-stage machines were constructed to serve these needs. With the advent of torpedoes in naval warfare, 3000-pound compressors were designed, but these were small-capacity, compact units in keeping with the limited space aboard submarines and other naval vessels.



Bettmann Archive Print

STEAM COMPRESSORS OF 1885

An exhibit of Rand Drill Company compressors and rock drills at the New Orleans Exposition. A description published at the time stated that to absorb heat of compression the air cylinders "are of hard brass, owing to its better conductivity, and as thin as is consistent with safety. The cylinder heads are hollow and have water circulating through them. The piston and piston rod are also hollow and, by means of a telescopic arrangement of tubing at the back end, are kept supplied with cold water. The piston packing consists of four composition rings arranged in pairs at each end of the piston. Before escaping, the water is made to pass between these rings completely around the piston in contact with the inside cylinder walls."



EARLY SYNCHRONOUS-MOTOR COMPRESSOR

A 200-hp. synchronous-motor-driven compressor installed about 1908 at the Dos Estrellas Mines of El Moro Mining & Development Company in Mexico. The motor was started and brought up to speed by an auxiliary 50-hp. induction motor, which was then disconnected by disengaging the driving gear.

High-pressure synthesis, which created a demand for still higher pressures, had its real beginning in World War I when the Haber-Bosch process for the fixation of atmospheric nitrogen was developed in Germany for the production of ammonia from which to extract nitrates for the making of explosives. The gases nitrogen and hydrogen can be combined at low pressure and temperature to form ammonia, but the percentage of conversion mounts as pressure and temperature are increased. The Germans built most of their plants to operate at 175 atmospheres (2625 pounds) pressure and 932°F. temperature. The reaction takes place in the presence of a catalyst and, in view of recent developments, it is interesting to note that the first catalyst used was powdered uranium. Iron filings were afterward found to be suitable.

The Haber-Bosch process has been adopted or modified by many nations, and some plants, including at least two in the United States, operate at pressures up to 15,000 pounds. Nitrogen, either alone or in combination with other elements, enters into the manufacture of explosives, fertilizers, dyes, plastics, etc., and high-pressure synthesis is required in con-

nection with all of them. High-pressure processes are also steadily entering the chemical, food, and petroleum-refining industries. Compressors for high-pressure service are usually specially built in accordance with the conditions governing each application.

Because the science of pneumatics deals with the mechanical properties of gases, regardless of their pressure, it is proper to include in this article something about vacuum. A perfect vacuum has, of course, never been attained, and the word commonly signifies pressure below atmospheric pressure at any given location. A vacuum pump is essentially a compressor acting in reverse.

Ctesibius, Hero, and other ancients knew of and applied vacuum, as we have already noted. In a treatise on pneumatics, Giovanni Battista della Porta, in 1601, described how steam could be condensed in a closed vessel to induce a vacuum and how the latter could be used to draw up water from a lower container. The first serious studies of vacua were made by Otto von Guericke, who, after serving as burgomaster of his native Magdeburg in Prussian Saxony, devoted much of his time to scientific investigations, especially in the field of pneumatics. The work of Galileo, who proved that air is ponderable, and of Torricelli, who discovered the principle of the barometer, led him to attempt to create a vacuum.

Von Guericke's original scheme was to fill a vessel with water, then pump the water out, thus leaving an exhausted space. After many efforts he invented an air pump in 1650. With this apparatus he performed the celebrated experiment of the Magdeburg hemispheres before Emperor Ferdinand III at Regensburg. Two copper hemispheres, about 22 inches in diameter, were laid together to form a sphere, a ring of leather soaked in oil being placed between them to form an air-tight joint. The air was then exhausted through an opening that could be closed by a tap. Under those conditions it was found that two 8-horse teams, pulling in opposite directions, could not separate the hemispheres.

In 1690, Denis Papin suggested condensing steam, previously expanded in a cylinder, to raise a piston, thus creating an atmospheric engine. Thomas Newcomen's engine of 1705 worked on that principle, the steam being condensed by a jet of water introduced into the cylinder. James Watt, an instrument maker in Glasgow, while repairing a model of Newcomen's engine in 1765, saw that it was very wasteful of steam and improved it by adding a separate condenser. To maintain a vacuum in the latter he used an air pump to extract air, water, and vapor.

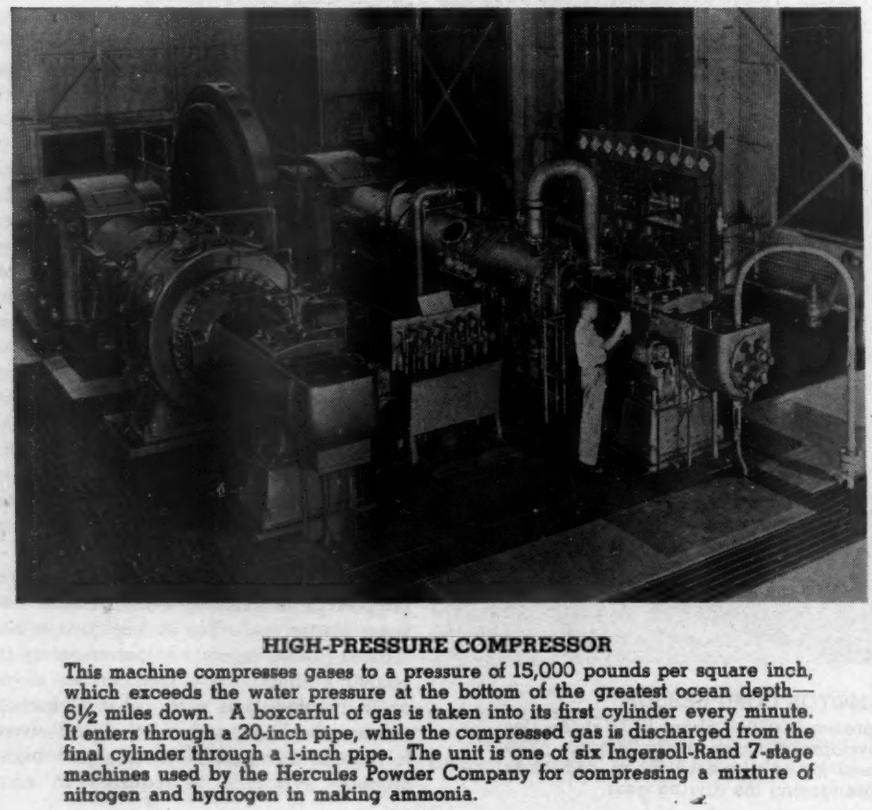
The invention of a mercurial vacuum pump about 1850 paved the way for studies of electricity in rarefied gases. These led to the electron, on which the science of electronics is based, and to a host of other discoveries in the field of atomic physics. It was while he was conducting experiments of this kind with a highly exhausted tube that Roentgen recognized X-rays. His attention was called to the fluorescence of a barium platinocyanide screen lying near the tube. Further investigations revealed that the radiations could pass through various substances and that they affected a photographic plate. X-rays had been produced before, but not recognized. Incandescent and fluorescent lamps and radio tubes are other outgrowths of this line of research. The *Encyclopaedia Britannica* states: "It would, perhaps, not be too much to say that the physics of the vacuum dominates the modern laboratory."

Commercial vacuum pumps are of various types, depending upon the character and working conditions involved and upon the degree of vacuum required. Conventional reciprocating dry vacuum pumps are generally similar to compressors in construction and appearance. There are also many kinds of rotary vacuum pumps, as well as special types for laboratory work and chemical processes that call for extremely high vacuums. In numerous industrial applications where steam is available vacuum is induced with steam jets, which act upon the aspiratory principle.

The services performed by vacuum in industry are legion. It is used throughout the food, chemical, and processing industries in evaporation processes, for dewatering various suspensions in connection with filtration, for evacuating many types of tubes, and in countless other ways.

Latest design of direct-acting high pressure duplex compressor

(From our June, 1897, issue)

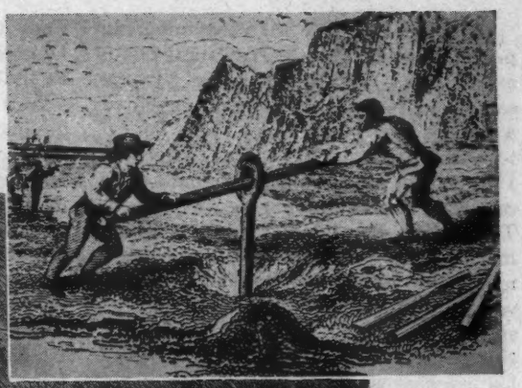


HIGH-PRESSURE COMPRESSOR

This machine compresses gases to a pressure of 15,000 pounds per square inch, which exceeds the water pressure at the bottom of the greatest ocean depth—6½ miles down. A boxcarful of gas is taken into its first cylinder every minute. It enters through a 20-inch pipe, while the compressed gas is discharged from the final cylinder through a 1-inch pipe. The unit is one of six Ingersoll-Rand 7-stage machines used by the Hercules Powder Company for compressing a mixture of nitrogen and hydrogen in making ammonia.

Rock-Drill High Lights

Bettmann Archive Prints



HAND DRILLING
Two of the laborious methods that were used before mechanical drills were available.

THE rock drill is strictly an American conception. Nearly all the early inventors worked in this country, most of the important improvements in drills were made here, and American designs have been universally adopted. The total mental effort expended on rock-drill technology defies estimation. In an article written by W. L. Saunders in 1889, he stated: "The rock drill embodies more inventions for its volume and weight than any other machine of equal importance." More than half a century has elapsed since then, but the statement probably is still true.

The natural and most effective way to drill a hole in rock is to strike a steel bit with a hammer. This is the method the hand driller used and is the motion the drill designers sought to duplicate mechanically. The early inventors didn't know how to accomplish that. In their machines, the entire drilling element, plus the piston, moved back and forth, producing a jabbing action. It took almost half a century for them to find a way of divorcing the two parts and thus to revert to the principle exemplified by hand-hammering. Many men tried to develop a hammer drill. J. George Leyner of Denver, Colo., finally achieved that goal in 1897 and gave the world a tool that was the basis of the present design.

This article will give the high lights of rock-drill history and trace the development of certain types of drills or drilling arrangements that have not been covered previously, or at least recently. For the sake of the record we will set down in chronological order the pioneering efforts that contributed to the evolution of the first workable drills.

Richard Trevithick of Cornwall, England, who built the first steam locomotive ever to haul passengers and who was also a pioneer in the steam-engine field, invented a rotary steam-driven drill in 1813. It was used principally in limestone.

In addition to hammering a chisel by hand to drill holes in rock, men of the pre-mechanical era did that work by lifting a heavy, pointed bar of steel and allowing it to drop of its own weight. These were known as drop or jump drills. In an effort to simulate this motion without expending muscular energy, the Singer Brothers, John A. and Isaac M., devised a tool in 1838 that was elevated by a steam piston and permitted to descend by gravity. They used a dozen of this type on the Illinois & Michigan Canal 30 miles from Chicago, and later at Lockport, N. Y., during the enlargement of the Erie Canal. These machines were obviously useful only for putting down vertical holes. The Singer Brothers did not figure in rock-drill technology thereafter, but Isaac subsequently wrote his name indelibly in American industrial history by designing the sewing machine that bears his name.

In 1844, Brunton, in England, suggested using compressed air for drilling, and invented what he called a "wind hammer."

In 1849, J. J. Couch of Philadelphia patented a percussion drill actuated by steam and mounted on a frame atop a boiler that was set on a 4-wheel carriage. A wheel, rotated through the medium of a ratchet, built up the momentum by which the drilling bar was hurled lancelike at the rock face. It was the first drilling mechanism with an automatic valve; the first that did not depend solely upon gravity for the drilling stroke; and the first that could be directed other than downward.

Couch's assistant, J. W. Fowle, patented a machine in 1851 that was the first to propel the drilling bar by the direct action of steam or air upon a piston, as contrasted with the Couch method of using an auxiliary engine. Fowle also attached the drilling bar to a crosshead, abandoning the idea of throwing it like a lance. Rotation was achieved with a ratchet-and-pawl mechanism. Likewise in 1851 Cavé obtained a patent on a drill in France. His machine was turned manually by means of handles, and the stroke was reversed with a hand-operated valve. It was consequently slow and not a commercial success.

In 1853, William Pidding invented a steam drill that was secured to a frame. At about the same time, Schumann in Germany made a drill for use in the Freiberg mines.

Some authorities believe that the steam hammer designed by James Nasmyth, Scottish engineer, was the inspiration for the first percussion drill. Nasmyth conceived that mechanism in 1839, but it was not placed in service until 1842. Twelve years later, before the British Association for the Advancement of Science, Nasmyth announced that he planned to build a machine on the steam-hammer principle. It was tried out in gypsum quarries near Paris, where hand-turned rotary drills or augers were in use. Steam was admitted at one end of the piston only and there was no provision for rotation.

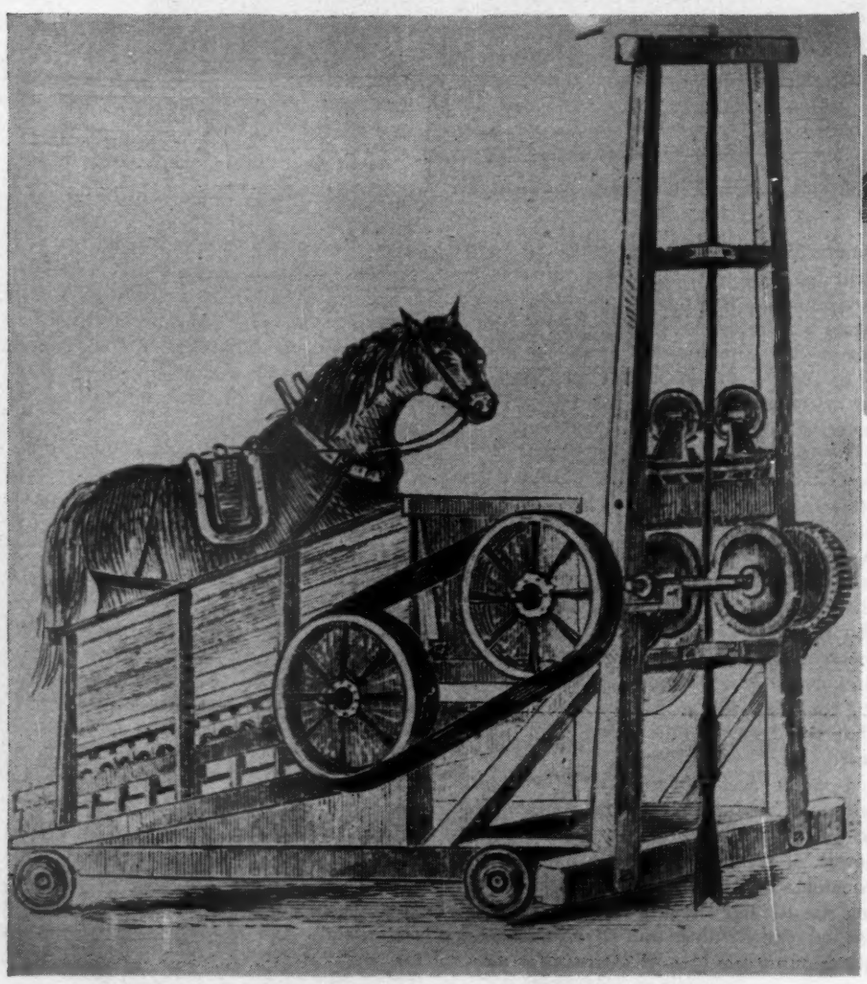
In France, in 1855, M. Fontainmoreau patented an air-operated drill that had a rotary and a forward movement. In the same year Bartlett, in England, invented a drill for work in the Mont Cenis Tunnel to be driven through the Alps. It was in 1861 on that project that mechanical drills received their first extensive service test. The records do not indicate clearly whose machines were on the job, but they were modified by M. Sommeiller and associates who suggested utilizing air drills and designed the compressors that supplied them with air. In 1861, Lisbet applied his machine to soft rock, and the Sachs drill was invented in 1863.

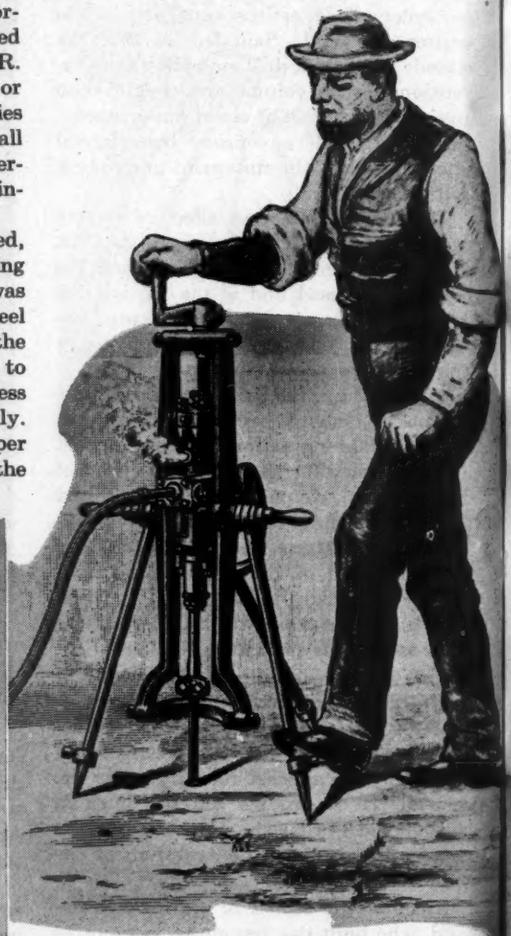
In 1866, Charles Burleigh, John W. Brooks, and Stephen F. Gates built a machine of the Fowle type for use in the Hoosac Tunnel, first American bore to be driven with mechanical drills. The drilling bar of this tool was rigidly attached to the piston, the crosshead being dispensed with. Some 40 of these machines were put in service. They weighed 240 pounds each and struck around 200 blows a minute. Their use was discontinued because of excessive breakage. Burleigh thereupon redesigned the drill. He provided it with means for rotating the piston and, consequently, the drilling bar. This machine proved fairly satisfactory but infringed upon the Fowle patents, which were then purchased. In Europe, the Dubois and Francois drill was first made in 1867.

Most of the drills so far mentioned were designed for mining and tunneling and were mounted on carriages. When Simon Ingersoll invented his machine in 1871 he mounted it on a tripod equipped with leg weights to hold it steady and thus made drills applicable to contracting work. Ingersoll's machine was based fundamentally on the Fowle-Burleigh patents, and these were purchased by the Ingersoll Rock Drill Company at the time it was formed. The Rand Drill Company was organized in 1873 to build drills designed by Addison C. Rand, J. C. Githens, J. R. Reynolds, and M. Stannard. Then, or perhaps a little later, other companies were started in the United States and all made piston-type machines. The Ferroux and the Darlington drills were invented in Europe in 1873.

Until the first Fowle drill was designed, the operation of virtually all reciprocating machines such as engines and pumps was assisted by the momentum of a flywheel transmitted through a crank. One of the greatest obstacles the inventors had to hurdle was that of creating a wheelless tool that would function satisfactorily. This resolved itself into a matter of proper valving, because it was necessary that the steam or air be admitted alternately at the ends of the cylinder to keep the piston moving back and forth. The valve action still remains one of the vital features on which the performance of a drill depends.

It was Henry C. Sergeant who made the Ingersoll drill a leader, and a large part of its success was attributable to the "Eclipse" valve that he incorporated in it. It is interesting to note that he got the idea for it from Adam Scott Cameron, a pioneer pump builder. Ingersoll drills and Cameron pumps were originally manu-





EARLY MECHANICAL DRILLS

A drop or jump drill was a long, pointed bar of steel that delivered its blow by the force of gravity. The picture at the left shows how a treadmill was used to operate it. The drill was rolled upward between two grooved wheels and then allowed to drop. As it fell, it was turned by the action of two other grooved wheels set at an angle to each other. This 1-hp. machine could, according to "The People's Journal," drill a 6-inch hole 20 feet in granite in a 10-hour day. It was patented by the North American Drill Company of Boston, which offered it "to assist those who have occasion to delve in the bowels of the earth." The comment was added that "the old-fashioned mode of drilling is nearly done with." At the right is an illustration of Gardner's patented steam drill of about 1860. It was modeled after Couch's original percussion drill of 1849. An Ingersoll lightweight piston drill of the 1885 era is seen above.

factured in the same little shop at Second Avenue and Twenty-second Street in New York. The first Ingersoll drill was arranged to effect mechanical contact through knuckle joints, rods, or other devices by which the piston reversed the valve at the end of its stroke. In his pump, Cameron used a small tappet to serve as a trigger that, by means of a trip, opened a small port connecting with one or the other end of the valve chamber. The valve was submerged in live steam, with the pressure normally equal on both ends. Tripping reduced the pressure on one end, and the greater pressure on the other end caused it to reverse. Sergeant had more of a problem, as the drill ran faster than the pump. Instead of using tappets, he moved his valve by causing the drill piston alternately to uncover passages leading to each valve end. The principle was the same in both cases and was used for many years on pumps and drills. Thus was born a close relationship between the Ingersoll and Cameron companies, and it has persisted through the years. The Cameron foundry supplied castings for the first Ingersoll compressors and continued that service as long as the two plants were together. After Ingersoll-Rand Company, successor to the Ingersoll concern, built its plant at Phillipsburg, N. J., in 1904, Cameron established one adjoining it. As a result of a merger of interests Ingersoll-Rand now owns both factories

From the early seventies until the advent of the hammer drill, the piston drill was steadily improved as the result of refinements in design and metallurgical advances. The rock drill is a machine that tends to pound itself to pieces, and its efficiency has always gone hand in hand with progress in steel technology. The first drills were run at 60 pounds pressure; but, in an effort to get more work out of them, users boosted it successively to 70, 80, and 90 pounds. To produce drills that would stand up, the manufacturers either had to make them heavier, which was undesirable, or get better materials. In the early machines the rocker pin, a part about the size of a man's little finger, broke so often that operators customarily started the day with a pocketful of them. The difficulty was overcome by procuring better steel.

This brings us up to the introduction of the hammer drill. Leyner did not invent it, for, as already stated, many men before him had had the idea and had worked on it. It is recorded that as early as 1865, George Low, an Englishman, patented a rock drill having a hammering piston. It had "a grasping handle with a manually operated throttle valve within the control of the operator's fingers." In 1884 a hammer-drill patent was issued to Sergeant, but the machine was not successful because it used solid drill steel and did not clear the hole of cuttings. It was discarded at the time, but later was made the basis of the Little Jap drill of the Sergeant company. Also during this same general period—the exact date is not given, the Franke drill of German invention appeared at the Mansfeld copper mines in Germany. Some said it was the first hammer drill tried out underground. It was reported to have a "bewildering" number of parts and to be designed to strike as many as 8000 blows a minute. It weighed about 16 pounds and was not practical.

The first hammer drill that was acceptable to the trade was a stoper invented in 1890 by C. H. Shaw of Denver. It was equipped with an air-feed leg which held it against the working face, so Shaw can be credited with two important contributions to drilling equipment. His machine used solid steel, but as it drilled only inclined holes, the cuttings worked out by gravity.

Leyner made the hammer principle operable for all types of drills by introducing hollow steel through which he directed a stream of air to remove cuttings. He sold 75 of these machines in 1897, but workmen refused to run them because they created so much dust. Living up to his guaranty, Leyner thereupon took them back and refunded the purchase price, even though it almost bankrupted him. He solved the dust problem by passing water through the steel, along with the air. Other Denver drillmakers who were working on the hammer-drill idea at the same time it was engaging Leyner's attention were D. S. Waugh, Walter & Brothers, and Illers. Any or all of them may have anticipated Leyner in some details of design, but he was the only one to take the over-all conception and bring forth a commercial product.

Leyner's drill does not seem to have been widely known for a considerable period after it made its appearance. Meanwhile, another type of hammer drill was put on the market and beclouded the issue for a time. This was the so-called air hammer, which was little more than a pneumatic riveting or chipping hammer equipped with a handle and fitted with a rock-drilling bit. It was much like the coal puncher that had been introduced into mines and weighed 20 pounds or less. One writer called these machines "the offshoot of the frenzied claims of pneumatic tool builders who were trying to find an outlet for their over-production." They were properly plug drills and were suitable only for putting down shallow holes such as those in plug-and-feather work, hitches in mines, etc.

The machines were not built to rotate the drill steel. It was rotated either by hand with a wrench or by turning the entire tool. Leyner seems to have been concerned not so much with these small drills as with the application of the hammer principle to larger drifter-type machines for mining work, and that is probably why his products were slow in becoming known.

These small tools cut quite a figure in the mining industry for a time. Although they created dust and were unsuitable for heavy work, they had so many advantages over the earlier unwieldy piston drills that they were widely adopted. Eventually, however, Leyner's superior machines received the recognition they deserved, and it became the practice to employ plug drills only for the light drill-

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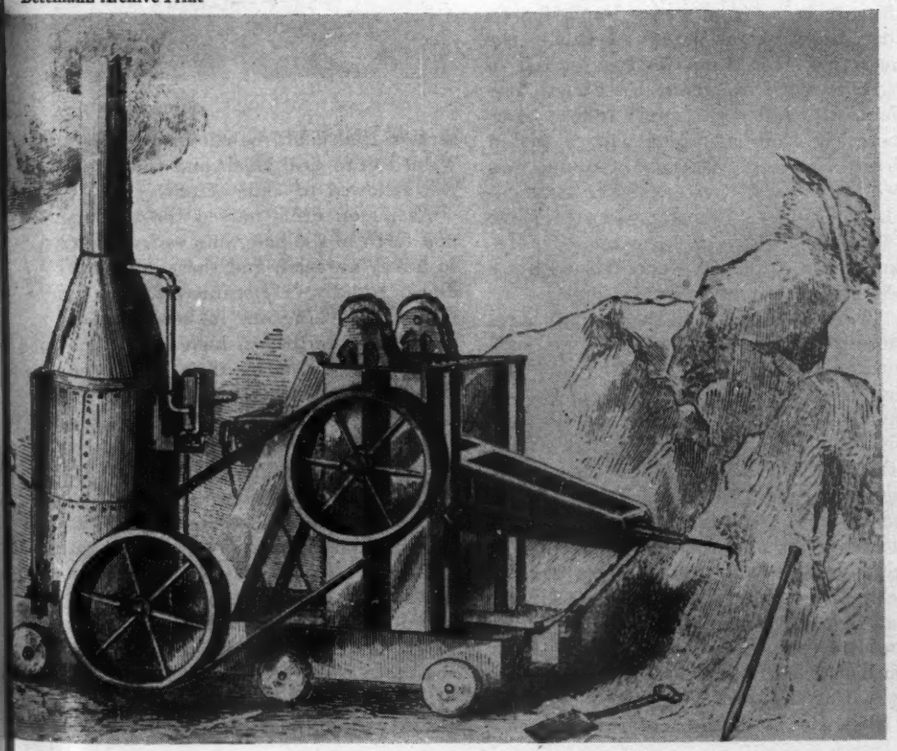
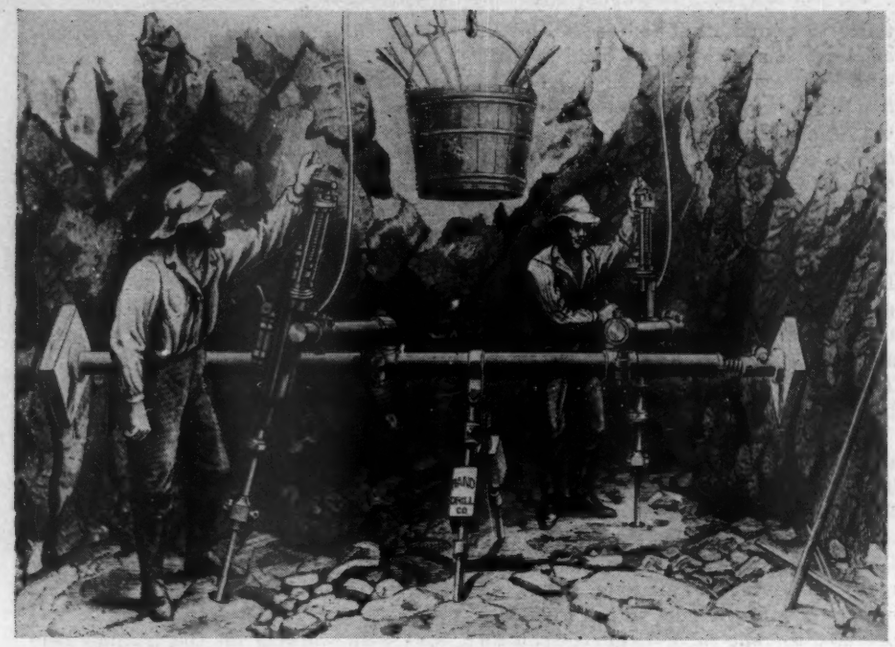




ing operations for which they were fitted.

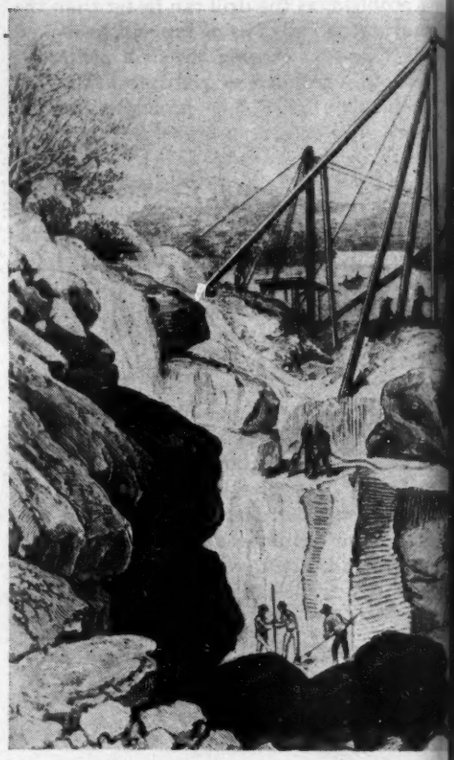
Custom being a strong influence, a long time elapsed before hammer drills displaced piston drills for heavy work. Contractors, especially, specified heavy machines because they knew that they would withstand the high air pressure that was needed for a heavy blow and that they were durable and did not run up high repair bills. They were cumbersome underground and required several men to move them. Yet they persisted for a long period. This led to a good deal of confusion, and as late as 1913, after the hand-held Jackhamer that was capable of putting down deep holes had been introduced by Ingersoll-Rand Company (which acquired Leyner's patents in 1912), there were five distinct types of drills on the market. These were the hand-held plugger drill, turned by hand; the Jackhamer, with automatic rotation; the stoper; the mounted Leyner type which predominated for tunneling and mine drifting work; and the heavy, so-called reciprocating machine that was used for deep down-hole drilling. Proof of the general superiority of the Leyner design came, however, when, upon the expiration of his basic patents in 1914, virtually all drill manufacturers began making machines based on his principle of construction.

The hammer drill excels the piston type for very sound and simple reasons. It is a natural air saver because it reciprocates a light plunger, whereas the piston drill must move backward and forward not only the heavy piston but also the drill steel attached to it. The work done by the drill bit depends upon the impact delivered at the bottom of the hole, and this can result either from a heavy mass moving slowly or from a light mass moving rapidly. In a machine of the piston type speed is limited, while in a hammer drill it is practically unlimited. Furthermore, because it is lighter and because of the nature of its action the hammer drill lends itself more readily to mounting than does the piston drill. The latter requires heavy columns, tripods, or carriages on account of its ponderous pulsations, whereas a light column or bar affords support enough to resist the comparatively light jarring effect produced by the rapidly shuttling piston of the hammer drill. For the same reason a hammer drill of the Jackhamer type can be held by hand, something a piston drill does not permit.

As these and other advantages of the hammer drill came to be known, the machine forged ahead steadily and was continually being improved. Reporting on that trend in the mines at Butte, the magazine *Mines and Methods* stated in 1910 that "Throughout the mines, one man will drill more ground with a hammer drill than two men with a piston drill. As a result, the cost of stoping has been reduced 25 percent. The Amalgamated Copper Company will soon have 300 hammer drills in operation. The repairs seem to be small and the machines seldom get out of order."

The chief obstacle in the path of hammer-drill success was the lack of a process for manufacturing hollow drill steel. The first of its kind was made of ⅞-inch stay-bolt iron and had a 6-inch hollow-steel bit welded on one end and a shank on the other. Crystallization at the welds caused frequent breakage. The next step was to drill a ⅜-inch hole in a 4-foot steel bar in a gun-barrel lathe. Steels were produced in that way for several years and were satisfactory except for the fact that they were limited in length. The problem was solved when steel mills learned to roll hollow steel, first in Sheffield, England, and later in this country.

Since the bit is the actual drilling element, it naturally has come in for much attention in the course of the years. The chisel bit of the hand driller gave way to the 4-point cross bit when power drills became available because there was less tendency to follow seams or slips in the rock that might result in crooked holes. Subsequently, 6-point, Z-, and other forms of bits were added. Bits were forged by hand, and to provide stock that could be worked on later, the end of the steel was usually upset for a distance of 6 or 8 inches. This was expensive, so some large mines put in bolt-upsetting machines. Eventually, mills rolled bars of larger



section that could be cut into pieces and welded onto drill steel, and this practice was followed to some extent.

As piston drills moved the steel back and forth in the hole, bits were subjected to heavy abrasion and the gauge was reduced rapidly. Because of this, and because of variations in bits formed by hand blacksmiths, ¼-inch reductions in gauge between succeeding bits became the rule. Holes consequently had to be started large to insure bottoming them with diameters big enough to take stick powder. When hammer drills appeared, the bit stayed at or close to the bottom of the hole and there was less gauge wear. This made it feasible to reduce the gauge difference between bits, but the inaccuracies due to hand sharpening made it difficult to accomplish this. The situation called for machine sharpeners, and they came into being around 1902.

The records do not disclose clearly who was first in this field. Leyner worked on a

sharpener in 1902, laid it aside for more important things, returned to it in 1907, and built three sizes. During the next five years he sold 400 of them in all parts of the world, and there were periods during which nine out of every ten units purchased were of his make. Machine-forged bits were uniform, could be made two or three times faster than those turned out by hand, and made possible ⅛-inch gauge reductions that permitted starting with smaller-diameter holes. The over-all effect was to increase the work of the drills by an estimated 25 to 50 percent.

The next and latest advance in the drill-steel field was the development of detachable bits. Although some of the early drill designers had conceived the idea, it was first carried out in a practical way by A. L. Hawkesworth, a mechanical foreman for the Anaconda Copper Mining Company at Butte, Mont. Following the introduction of bits of this type, Anaconda made a study of them in one mine in 1927 and determined that, if they were used in all its Butte properties, a saving of $140,000 a year could be realized. This caused other large operators of drills to become interested, and since then the recognition of detachable bits has been rapid, especially in mining and tunneling work.

Among the principal savings effected by them are less transportation of drill steel between drilling places and blacksmith shops and a decrease in the amount of bar stock required. Separation of the bit and the drill rod permits the use of steel that especially meets the requirements of each member, whereas it was necessary previously to make a compromise. Today, the accepted method of reconditioning detachable bits is by hot milling, and efficient equipment has been developed for that purpose.

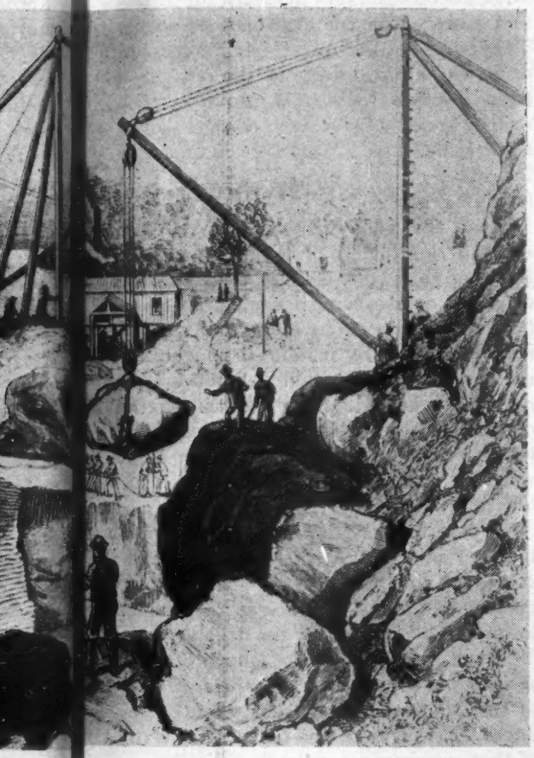
One of the principal offshoots of the hammer drill is the pavement breaker. The exact time of its introduction is uncertain; but it, or an intermediate type consisting of a modified rock drill, was used in 1911 by street-car and gas companies both in Zurich, Switzerland, and Brooklyn, N. Y., for tearing up pavements. Ingersoll-Rand Jackhamers of the butterfly-valve type were adapted for demolition work in connection with New York City subway construction in 1913. Because of the similarity between their work and that done by pickaxes, they were known as "butterfly pickaxes."

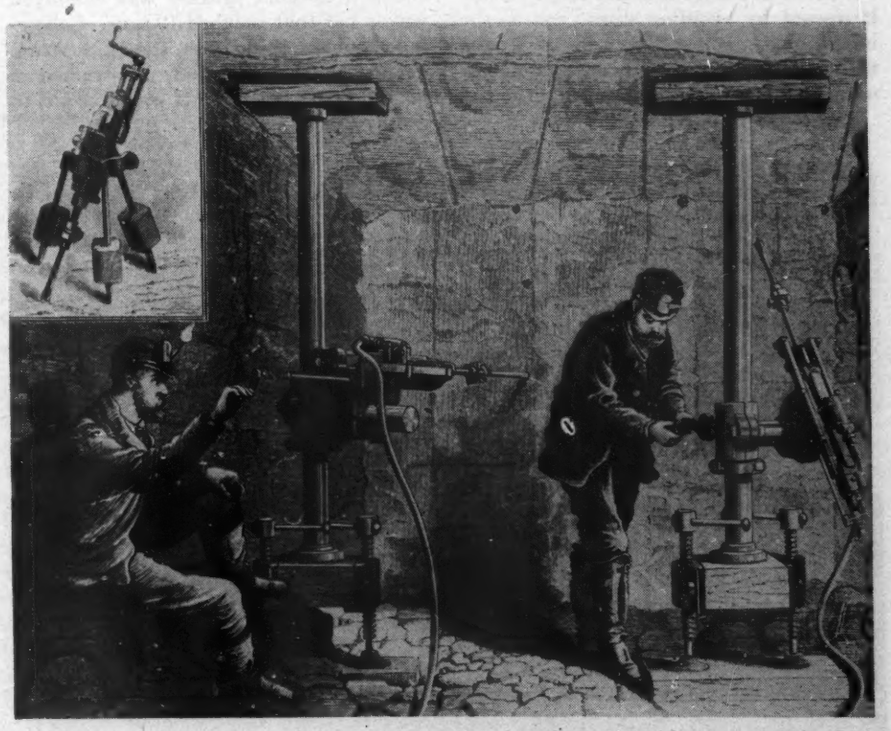
Another relative of the rock drill was the coal puncher, which was designed to cut a slot at the bottom of a seam, thus making it possible to bring the remaining section down easily. J. W. Harrison produced the first machine of this type in 1880 by laying a rock drill on its back, supporting it on wheels, and replacing the drill steel with a 2-pronged tool. Another coal-mining machine was the Radial-axe developed by Sergeant. It consisted of a rock drill mounted on a column and arm and was arranged so that it could be rotated in a horizontal plane.

Various attempts were made over the years to develop a practical electrically operated percussion drill, but without success. The so-called electric-air drill was invented in 1904 by Robert Temple, who connected both cylinders of a small electrically driven compressor to opposite ends of a rock-drill piston by means of hoses. This resulted in a pulsating action, the drill piston moving with each alternate stroke of the compressor cylinders. Although the compressor discharged at only 40 to 50 pounds pressure, the effect of the vacuum pulled on the opposite end of the drill piston as it made its stroke was to increase the power to the equivalent of 60-65 pounds pressure. The Temple drill was first used in Colorado mines, and later models, improved by Albert H. Gibson and manufactured by Ingersoll-Rand Company, were sold in many parts of the world for general work. This type of machine operated well so long as the hose lengths between the pulsator and the drill were limited to eight feet. Power decreased fast as this length was exceeded.

Hydraulic power also was tried but was abandoned. Brandt hydraulic drills were utilized experimentally in driving the Arlberg Tunnel through the Alps, 1880-83, and one end of the Simplon Tunnel, 1898-1905.

Various types of mountings have been designed for rock drills. The bar channeler for quarrying was first tried out in marble quarries at Sutherland Falls, Vt.,





OLD DRILLING SCENES

The top picture shows Rand drills sinking a shaft in 1880. In the center is an 1880 illustration of a Tennessee marble quarry. The view above shows Rand "Little Giant" drills working in one of the first New York bores—the Forty-second Street sewage tunnel. "Three were always in action and two under repair," the "Scientific American" reported. At that time (1877) there were six sizes of Rand drills, ranging in weight from 150 to 900 pounds.

where the air was supplied by one of the compressors that had previously served in the Hoosac Tunnel. The track channeler was next developed and is still employed in some quarries.

The wagon mounting has made the drifter drill applicable to deep-hole work in the contracting and construction fields and is now a highly maneuverable, pneumatic-tired drilling machine. One of the earliest uses of wheel-mounted drills was in 1909 at Grosse Isle, Mich., in connection with the digging of the Livingstone Channel. The area was enclosed within a cofferdam so that it could be excavated in the dry. Operations were started with four piston drills set on tripods. Steel had to be changed every 2 feet, or seven times to complete a 14-foot hole. The drills were being crowded to furnish spoil for one of the cable conveyors spanning the site.

In an effort to speed up the work, C. H. Locher, a member of the contracting firm and identified in recent years with the Tennessee Valley Authority engineering staff, devised a mounted machine. Heavy timbers, set on 4-inch-tread steel wheels, formed a frame for the drill, drill tower, air receiver, and a reversible hoisting engine for raising and lowering the drill in guides on a gallows frame. The machine had a travel of 10 feet in the guides and drilled to a depth of 8 feet with the same steel. It was operated by two men and replaced the four tripod drills and eight men. A descriptive article in our January, 1910, issue stated: "This drill has largely made its record by avoiding stops, just as the big through express trains do." It was then called a locomotive drill. Subsequent units of this type were known variously as autotraction drills and drill wagons.

The advance in underwater excavation has been as great as that on land, and a considerable share of the credit therefor must go to the rock drill. Ship channels the world over have had to be deepened continually to accommodate vessels of deeper draft, harbors have had to be cleared of obstructions, and docks of ever-increasing size have had to be constructed. In these and all other activities calling for the removal of submerged rock the rock drill has been of vital importance. In fact, it is difficult to see how some of the work could have been done without it.

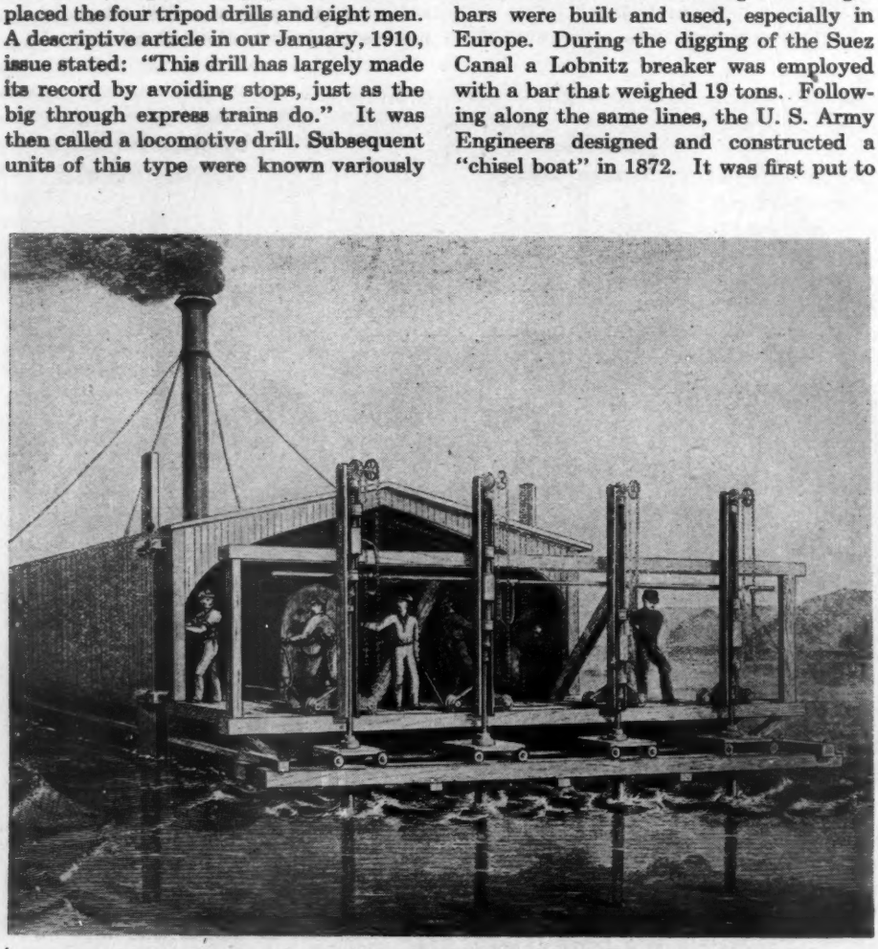
Before the mechanical rock drill was developed, rock removal below water was a slow and tedious process. Where the rock projected above the surface or, if submerged, was accessible from land, it was chambered by sinking shafts and driving tunnels with the aid of hand drilling and black powder. The chambers were then loaded and shot with enough explosives to shatter the entire mass to the depth to which it was to be excavated. Where this method could not very well be followed, long bars of iron with chisel points were bounced up and down by hand to fracture the rock by repetitive impacts.

Mechanical devices were next tried for lifting the bars, the weights of which were increased to as much as 4 or 5 tons. Still later, machines for handling even larger bars were built and used, especially in Europe. During the digging of the Suez Canal a Lobnitz breaker was employed with a bar that weighed 19 tons. Following along the same lines, the U. S. Army Engineers designed and constructed a "chisel boat" in 1872. It was first put to work at Rock Island Rapids in the Mississippi River and continued to serve until 1889 despite the fact that rock drills had been available for a long time. No explosives were required with these devices, the rock broken up by the chisels being removed with dipper dredges. Even the heaviest bars were not effective against real hard rocks, particularly those of igneous origin.

The invention of dynamite in 1867 made obtainable for the first time an explosive that could be used underwater, and the mechanical rock drill furnished a means of putting down holes in which to place it. The first subaqueous drills were necessarily the same as the land type—large piston machines mounted on tripods and operated for the most part by steam. They were set up on rafts or barges, but as it was difficult to hold the craft in a fixed position they were provided with anchor spuds, one at each corner. These floating bases were used for the first time in 1881 in clearing away Black Tom Reef in New York Harbor.

From this type of structure gradually evolved the modern drill boat with steel hull and movable drill towers. Piston drills, of course, served exclusively until hammer drills were invented and are still employed in many instances, notably for relatively shallow drilling. As ship channels were repeatedly deepened, the lengths of the drill steels required to put down holes became so great that some of them weighed as much as 900 pounds, thus creating a handling problem.

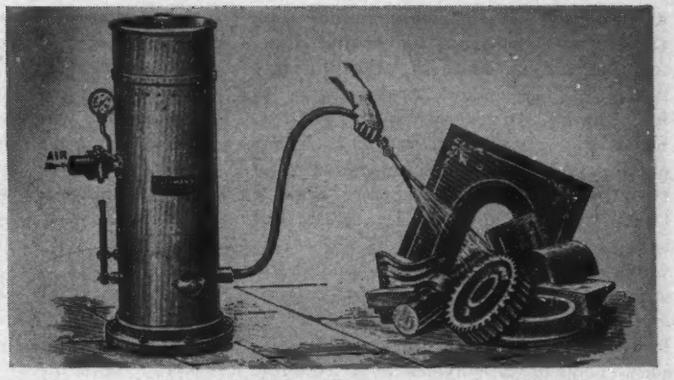
To overcome the difficulty, submergible hammer drills were substituted for machines of the piston type. The former operate just above the rock surface, being lowered into the water on drill ladders. This not only lessens the length of steel needed but also permits the use of steel of smaller section and, consequently, reduces the weight to one-fifth or one-sixth of that previously required. This change has resulted in faster drilling, especially as the hollow steels of the hammer drills make it possible to clean holes readily during drilling and prior to blasting. Boats equipped with piston drills sometimes still use steam power; but as this is not suitable for underwater hammer drills, craft carrying the latter type also have compressor plants aboard.



SUBMARINE DRILLING

The first drill scows had holes in them through which the drills operated. Shown here is the "improved" Rand scow with a runway on one side along which the mounted drills were moved. This craft was used in 1878-79 in deepening the channel of the St. Lawrence River near the Lachine Canal.

Early Pneumatic Tools

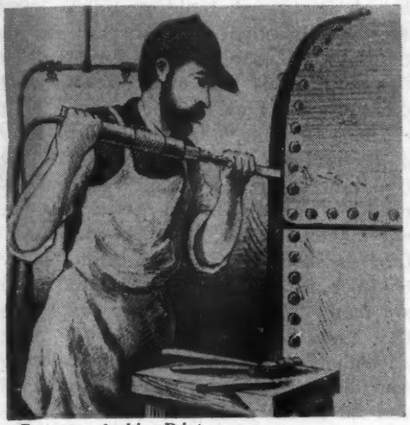


SANDBLASTING IN 1895

Cleaning castings with a Ward & Nash machine. Sandblast equipment was introduced around 1870 and was designed for cleaning the exteriors of masonry buildings. Its use in American foundries dates from about 1890. In 1916, "blackboards" made by sandblasting glass and painting it black were placed in Portland, Oreg., public schools.

1889 CHIPPING HAMMER

The first pneumatic tools used in industry were apparently designed for chipping stone and metal, but riveting hammers were developed soon afterward. The illustration below is from an old woodcut.



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CYLINDER HOIST

This reproduction from our October, 1896, issue, shows the first pneumatic type of hoist to serve in place of the chain hoist. It was used in railroad shops, foundries, and other branches of the manufacturing industry. The unit was suspended from an overhead rail and was employed by a New York firm for unloading goods from delivery drays and moving them to storage places.

THERE are two general classes of portable pneumatic tools: first, percussion tools such as riveting hammers in which a piston or plunger strikes the blow against the working tool; and, second, motor-driven tools such as drills, grinders, and hoists in which the motion is rotary. The first class made its appearance before the second, the earliest tool of record having been a diminutive hammer that served to tamp gold fillings in teeth. It was called a dental plugger and seems to have originated in England, probably in the 1870's. It was introduced into various countries, and dentists in the United States were using it extensively around 1900.

There is every reason to believe that the larger pneumatic hammers were developed from this miniature tool. The fact that air-operated rock drills were already in service may have spurred on early tool inventors; but those drills were of the piston type, a design that did not lend itself to adaptation so far as the smaller tools were concerned. The truth, probably, is that the pneumatic hammer was responsible for the change in rock-drill design from the piston type to the hammer type that is now in general use.

It is difficult to determine who produced the first pneumatic hammers. The American Pneumatic Tool Company started making them in 1883 or earlier, using McCoy and Bates patents. The Electric & Pneumatic Tool Company of New York began their manufacture in 1887 under the Drawbaugh patents. Some sources give McCoy credit for having been the first man to apply hammers to heavy work such as chipping metals, calking boilers, and cutting stone. He was awarded a medal for a "new and meritorious invention of real utility" by the Franklin Institute of Philadelphia in 1889, following an exhibition of his tools there. The latter seem to have been of various sizes, for it was mentioned that they were utilized for calking, chasing silverware, stone dressing, and sculpturing. About one of the tools on display, the Institute's Committee on Science and Art reported:

"It was working at a very high speed, from the pitch of the sound probably more than 5,000 strokes per minute. In the piston, but working transversely through it, is a piston valve, which is worked by the pressure of air admitted through a port in the side of the cylinder and exhausted through other ports in the same manner as the piston valves of some steam pumps, the proper ports being covered and uncovered by the motion of the piston. The valve consists of a cylindrical plug having two grooves formed therein with a collar between them, and fits in a cylindrical transverse seat in the piston and covers and uncovers, at proper intervals, admission and exhaust ports leading to the ends of the working cylinder."

In a paper read before the Coventry Engineering Society in England on January 23, 1914, H. L. Brackenbury stated that "The first serious attempt to produce a practical metal-working hammer seems to have been made by Joseph Boyer of St. Louis, who, in 1883, patented a chipping machine with a grasping handle and a throttle valve controlled by hand." According to the same source, Benjamin Brazelle of St. Louis obtained a patent in the early 1880's on a steam pump having a differential piston attached to a plunger, together with a differential-area valve, each of which served to control the operation of the other. Boyer later incorporated this design in a metal-working pneumatic hammer, but modified it to suit the conditions imposed by chipping, calking, and riveting. Another British writer, John Holloway, wrote in *The Engineer* (London) of December 29, 1939, that a valve similar to Brazelle's was embodied in Doehring's rock drill of 1867 and could well have established the valve principle on which pneumatic tools now operate.

After the first tools had been in use a few years, it became apparent that there was a large field of service for pneumatic riveting hammers, and this led to the invention of tools in which a comparatively short piston was caused to travel a distance much in excess of its own length. It is generally conceded that the first of these long-stroke hammers was made about 1899 by Boyer, who fitted a valve at each end of the cylinder and connected them by two small rods placed in longitudinal passages drilled in the cylinder walls.

At about the same time, air motors were applied for the purpose of developing rotary motion for turning twist drills in working wood and metal. Those motors were of the piston type, for vane-type motors were introduced in comparatively recent years.

The Q & C valveless tools were well known around the turn of the century, being utilized chiefly for light chipping

and calking. A somewhat similar tool, the Kotten, was made for carving stone, for die sinking, and for other delicate work. It had a short stroke—¼ to ½ inch—and it struck as many as 10,000 blows a minute. Pneumatic tools for cutting and dressing stone were advertised by William Wolstencroft's Sons & Company of Philadelphia, Pa., in the first issue of this magazine, March, 1896. Advertisements of the Keller "pneumatic stone and metal cutting tools," manufactured by C. H. Haeseler Company of Philadelphia, appeared in our 1897 issues. Tools of the valveless type were not strong enough for heavy chipping, riveting, etc., so hammers were built with a controlling valve to give them a longer stroke and higher piston speeds.

Railroad shops were among the early users of air-powered tools, which came about as a natural consequence of the employment of air brakes on railroad cars. Roads that had some air-braked freight cars maintained repair yards provided with air lines for testing brakes. The air was supplied by Westinghouse steam-driven "pumps" of the same type that was utilized for train air-line service. With air thus made available, the yards found various ways of using it. One of the first of its applications was that of forcing couplings into air-brake hose, and a few shops had air jacks for raising cars and locomotives to facilitate the work of repair. As the pumps furnished only relatively low-pressure air and were of small capacity, as many as six or eight of them were often required to meet the demand. Even then, there was such a shortage of air as to restrict its use. Later on, when the economy of air tools had been recognized, industrial-type compressors were placed in many of the yards.

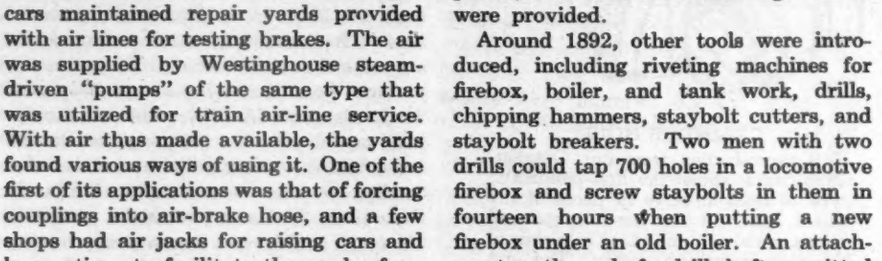
By 1891 some lines had equipped themselves with air jets to blow dust from passenger-car window sashes and blinds and to reach into corners and other spaces that could not be conveniently cleaned with the feather duster then in vogue. A round nozzle with a 3/32-inch opening was usually employed for the purpose. Next, a flat nozzle was made for cleaning cushions and backs of seats in Pullman cars and, afterward, bedding, carpets, etc. In railroad machine shops, the first air-powered appliances were small pneumatic, cylinder-type hoists which replaced chain blocks on all machines working on heavy pieces. As a great many hoists of this kind were put in service, the shops often made their own, fashioning the cylinders from lap-welded wrought-iron pipe and fitting them with cast-iron heads. Leather packing was used for the piston, and inlet and discharge valves were provided.

Around 1892, other tools were introduced, including riveting machines for firebox, boiler, and tank work, drills, chipping hammers, staybolt cutters, and staybolt breakers. Two men with two drills could tap 700 holes in a locomotive firebox and screw staybolts in them in fourteen hours when putting a new firebox under an old boiler. An attachment on the end of a drill shaft permitted screwing in bolts without a square shank and thus eliminated the necessity of forging a square head on them. The pneumatic drill soon supplanted the flexible shaft and ratchet for drilling holes in locomotive boilers and frames.

But railroad shops found many other applications for compressed air. An air motor was used in connection with a cylinder boring bar for boring and grinding cylinders. In finishing passenger-car woodwork, sandpapering with air tools replaced the manual method because it was cheaper. In cars that were equipped for gas lighting, old paint was removed with a torch—by directing a jet of air and gas through a Bunsen burner. Paint was mixed by agitating it with air, and both paint and whitewash were applied by air spray. A building 150x200 feet was whitewashed in that way in ten hours, and soon all whitewashing of fences, bridges, and structures at road crossings was done by spraying.

n a talk before a railroad club in 1896, J. H. McConnell, superintendent of motive power for the Union Pacific Railroad at Omaha, Neb., reported that "In our machine shops, air is now as important as steam. It is performing many things better than steam did, and there are many tools about a shop run by air that could not be run by steam." After a locomotive had been repaired, the boiler was filled with air at 100 pounds pressure and all steam passages in the cylinders were blown out. The pistons were then put in, the boiler was again charged with air, and the locomotive run out to the roundhouse. This obviated building a fire and waiting to raise steam, and no fuel was consumed. Staybolts were tested by filling the boiler with 100-pound air and sounding the bolts with a hammer. From a 16-inch cylinder, an air press was made for the tin shop and served to cut out and flange pieces for the fabrication of galvanized buckets, oil cans, spouts, tallow pots, etc. Shears in the sheet-iron shop were operated with an air piston, forges were blown with air, and sand was elevated to storage pneumatically. In those days, a compressor that had the capacity of six air pumps sold for $800. In 1897, the master mechanics of the principal railroads estimated that air power had reduced shop-work costs by 25 to 50 percent. British railroads also pioneered the use of air tools, the first ones having made their appearance in the Swindon Works of the Great Western Railway in 1896. Most of them, if not all, were made in America, including Boyer hammers.

Boiler and machine shops, and then foundries and shipyards followed the lead of railroad shops in adopting air power, and it soon spread to other branches of industry. In 1900, one pneumatic-tool manufacturer issued a 158-page catalog. Air's first use in foundries was apparently for sandblasting and then for operating hoists, chippers, drills, sand sifters, molding machines, and other labor-saving devices. The original power rammers for foundry molds were large, weighty units that were suspended from overhead supports. The hand-held rammer was introduced around 1900. One of our 1901 issues stated that "the day is near at hand



AIR-OPERATED CRANE

This overhead traveling crane, equipped with three air-operated motors to carry out the different movements, was installed about 1894 in the main machine shop and erection room of the Ingersoll-Sergeant Drill Company, Easton, Pa. It had a rated capacity of 20 tons, a span of 40 feet, and a travel of 460 feet. Note how the air-delivery hose was suspended.

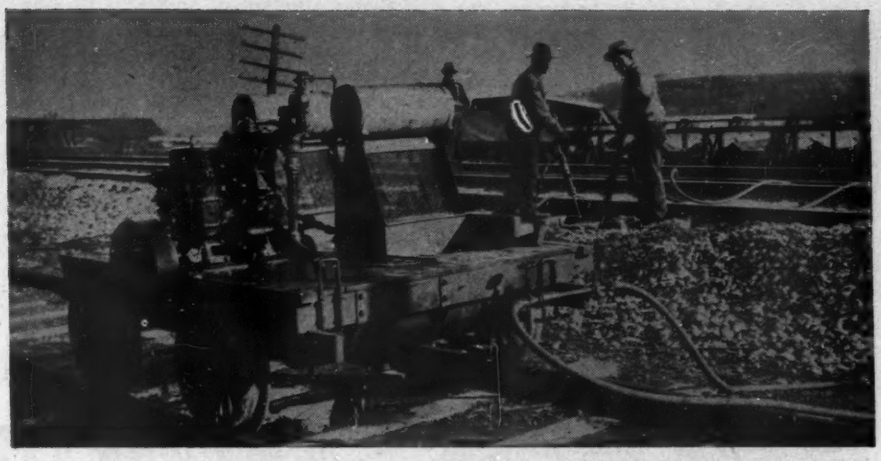
when a foundry without pneumatic equipment cannot produce its output in commercial competition with foundries that have adopted it." The magazine *Rock Products* reported in 1903: "Pneumatic tools and other modern appliances for working stone have come to stay. This is the time of year (September) when operators in the quarries look with favor on pneumatic appliances as compared with steam, for it is hot enough without the steam at work."

Pneumatic tools appeared in shipyards about 1897, when it became evident that compressed air could be piped around the yards without the loss incident to the use of steam. In 1901, Cramps in Philadelphia had 300 pneumatic tools and were putting in an air-compressor plant to deliver 17,000 cfm. The British Navy first resorted to air-powered tools in 1902, when H.M.S. *Assistance* was fitted out as a workshop for the fleet. The Russian Navy had adopted them the preceding year. In 1903, the Philadelphia Pneumatic Tool Company equipped Kaiser Wilhelm's new navy yard at Kiel, Germany, with tools of this type.

During this period, American-made pneumatic tools were being sold in many parts of the world, and our manufacturers found it of advantage to send not only salesmen but also executives abroad periodically. The president of one concern returned from Europe in 1902 with orders for 2700 tools and 25 compressors. European countries began to realize that they must employ labor-saving devices to produce industrial goods at competitive costs with ours. Shipowners had discovered that air-powered riveting was superior to hand methods and "the time was seen when they would ask all shipbuilders to use air riveting." Because pneumatic hammers spread rivets so as to fill the entire hole, they were being made ⅛ inch longer than previously when they were hand driven. Those put in manually could be knocked out readily, but the machine-driven ones had to be drilled out.

We have gathered from the foregoing that most of the development in the industrial application of air-operated tools has taken place in half a century and that the demand for them has grown steadily. The original tools have undergone much refinement and improvement, new ones have been added, and the fields of use have been continually widened. Welding at first appeared to be detrimental to the pneumatic-tool industry, as it presaged a decline in riveting. However, air tools perform so many auxiliary services in connection with welding that the overall effect has been to increase rather than to lessen their employment.

Among the present applications of pneumatic tools that are of importance but which were unthought of in the beginning is that of moving loose materials with hoist-powered scrapers. Although the latter have been widely used in work of this nature, their major single field is the mining industry, where the moving and loading of ore and rock is known as scraper slushing. The method was introduced about 1916, during World War 1, when a shortage of labor coincided with a demand for increased ore production. Underground slushing in metal mines is said to have been inaugurated in the Platteville division of the Tri-State zinc-lead mining district (Joplin, Mo., area). The Vinegar Hill Zinc Company made the initial installation, but slushing was employed soon after in the Lake Superior copper-mining region.



FIRST TIE-TAMPER OUTFIT

The picture was taken in 1913 during experimental work on the New York Central Lines near Roseton, N. Y. The compressor was an Ingersoll-Rand gasoline-engine-driven unit. In addition to supplying air for the two tie tampers it also furnished motive power for the hand car on which it was mounted. During the first few years tie tampers were in use some railroads operated them with air taken from the lines of the pneumatic signal system. These carried air at 110 pounds pressure, although the signals required only 60 pounds, so there was a surplus that could be drawn upon for the tools.

The great expense and the uncertain results of tamping ballast under railroad ties by hand led to the development of mechanical tampers, of which the pneumatic type was the earliest and is still the leader. In a paper written in 1898, it was stated by R. F. Coates, roadmaster on the New York, New Haven & Hartford Railroad: "As George Stephenson surfaced his track, so we do it today, theoretically and practically seeking to overcome the inequalities caused by train gravity in the foundation of our ties by pounding more material under them in resistance of that gravity." He said that track maintenance on United States railroads in 1895 had cost $69,000,000 and employed 185,000 foremen and sectionmen, or more than one per mile. The outlay was $200 per track-mile, or four cents per foot.

Around that time, a method of blowing ballast under ties with compressed air was being tried out and was subsequently used to a considerable extent. Mr. Coates, in reporting on the work, stated that a blacksmith's blower of the Roots type was found to be best adapted for conversion. The blower was turned by hand, two of the usual 4-man track gangs being required for that duty. Tie ends were barred up, and the ballast was blown under the sleepers with apparatus devised for the purpose. The ballast that could be readily handled in this way was of ¾ inch maximum size. In a test conducted on two adjacent stretches of track, fourteen rail lengths long, a hand gang tamped at the rate of 5 feet per man-hour, as compared with 8 feet by the blower.

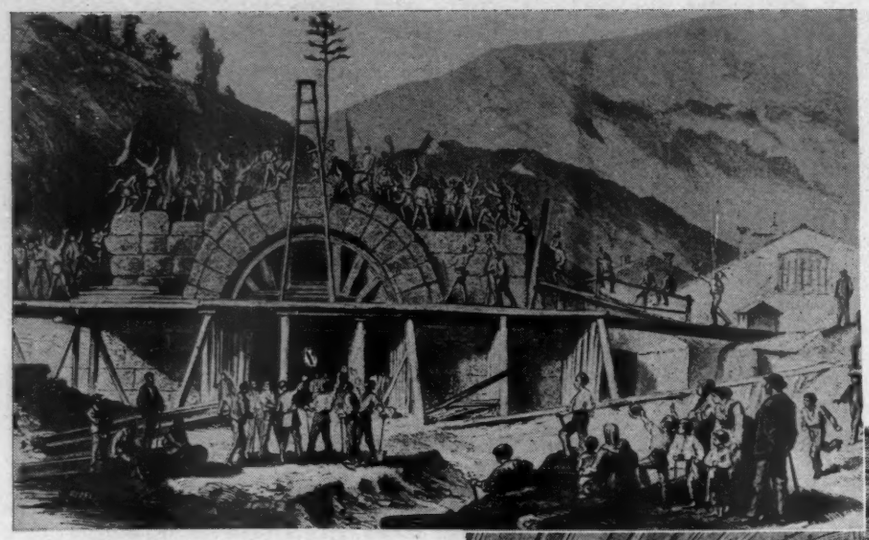
The first mechanical tamping tool was tried out on the New York Central lines in 1913 and was of Ingersoll-Rand manufacture. During the next two years many of the leading railroads adopted pneumatic tampers, with reductions in labor costs ranging up to 50 percent. By 1916 the Pennsylvania had 210 tampers. Pneumatic spike drivers and rail-bonding drills made their appearance in 1917.

The development of vane-type motors was a major forward step because it made possible not only a wider application of air-motor drive but also the production of rotary-type tools of smaller sizes but equivalent in power rating to those previously available.

Of the recent new tools, the impact wrench is perhaps of most importance to industry. It converts rotary motion into rotary impacts and has greatly speeded up bolting operations and similar work. The original tool of this type was the Pott wrench, which was introduced by Ingersoll-Rand Company in 1934.

The appearance of the all-metal airplane created a demand for small air-operated tools, especially hammers and drills, suitable for working on aluminum and in small spaces. New, high-speed units were designed with aluminum-alloy housings to reduce their weight and were made in large quantities during the recent war because they were especially adapted for use by women.

Tunneling Through the Ages



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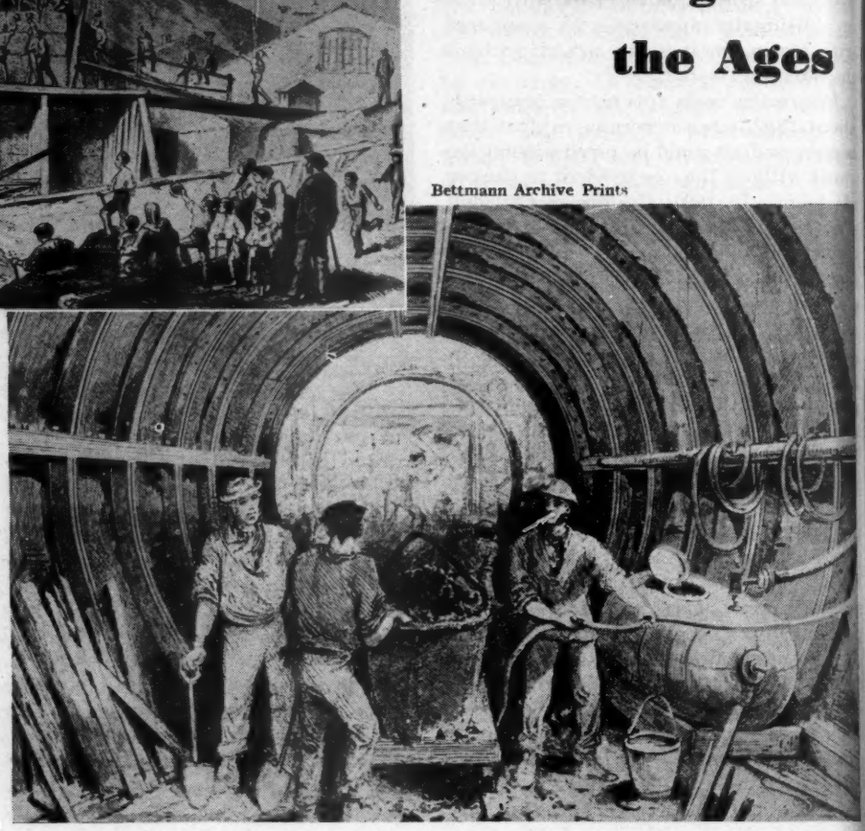


TWO HISTORIC TUNNELS

Pictured above is the scene at one of the Mont Cenis Tunnel portals as the last stone was laid in the presence of workers and officials in 1871. The other view shows work in the subaqueous bore of the London and Southwark subway in 1888.

TUNNELS have always been important in the affairs of mankind and, as they constitute one of the principal fields of application of compressed air, they have a place in the story being told in this issue. Tunneling goes back to antiquity, because it is safe to assume that the cave dwellers, with the crude tools they had, gouged out the niches in which they lived. Upon ascending the throne, every Theban king immediately began the work of driving a long, narrow adit to the rock crypt where he was to be buried. Some of these galleries were more than 750 feet long.

The first known tunnel under a river was built in ancient Assyria to satisfy the longing of Queen Semiramis for a passageway from her palace to the Temple of Jupiter, across the Euphrates River. Her engineers could not burrow beneath the stream, so they diverted it temporarily while they excavated a channel in which they constructed a 12x15-foot masonry tunnel. Another early Assyrian project of a similar nature was a masonry drain that was built by King Shalmaneser (860-824 B.C.) below the Palace of Nimrud.

The Hindus and Egyptians drove tunnels in connection with their temples and sepulchers, and there are remains of Egyptian works that go back to 1500 B.C. The Hebrews, Greeks, Aztecs, Peruvians, and Romans also practiced tunneling. The Romans were the greatest of all these early burrowers and have left examples of their art both in their homeland and in regions that they conquered. Their bores were used for transportation, drainage, water supply, and mining purposes, and some of those aqueducts and sewers are still in service. Pliny described what is believed to have been their first long tunnel, a 3½-mile gallery about 75 miles from Rome that carried off the overflow from Lake Fucino. Like most Roman underground passageways it penetrated limestone, which softened when subjected to the technique known as fire-setting.

It was the practice to build a wood fire against a heading and to dash cold water or vinegar upon the heated rock. This caused surficial flaking and disintegration

NOTABLE MONTHLY TUNNELING RECORDS IN ROCK

COMPARATIVE figures on tunneling progress can be misleading. There are numerous variables that affect speed of advance, and it is impossible to find two tunnels where all conditions are identical.

Name	Location	Type of Rock	Heading Size (ft.)	Month	Footage
Arlberg Tunnel	Alps	Schist, gneiss	8⅓x9⅓	July, 1883	641
Simplon Tunnel	Alps	Schist, gneiss	6½x9⅔	July, 1904	755
Gunnison Tunnel	Colorado	Shale	8x12	— 1908	842
Loetschberg Tunnel	Alps	Limestone, gneiss	6x10½	July, 1909	1013
Water Supply Tunnel	St. Louis	Limestone	10x10	Jan. 1914	744
Rogers Pass Tunnel	Canada	Slate, schist	6½x9	Nov. 1914	817
Priest Portal	California	Schist, quartzite	11¼x11¼	Aug. 1921	776
1000 Palms No. 1	California	—	19x19	Nov. 1935	1101
Delaware Aqueduct	New York	Schist	19x19	Feb. 1940	1863
Carlton Tunnel	Colorado	Granite	10x11	Mar. 1940	1879

The records for an 8-hour shift (27 feet) and for 24 hours (74 feet) were made in the Carlton Tunnel in 1940.

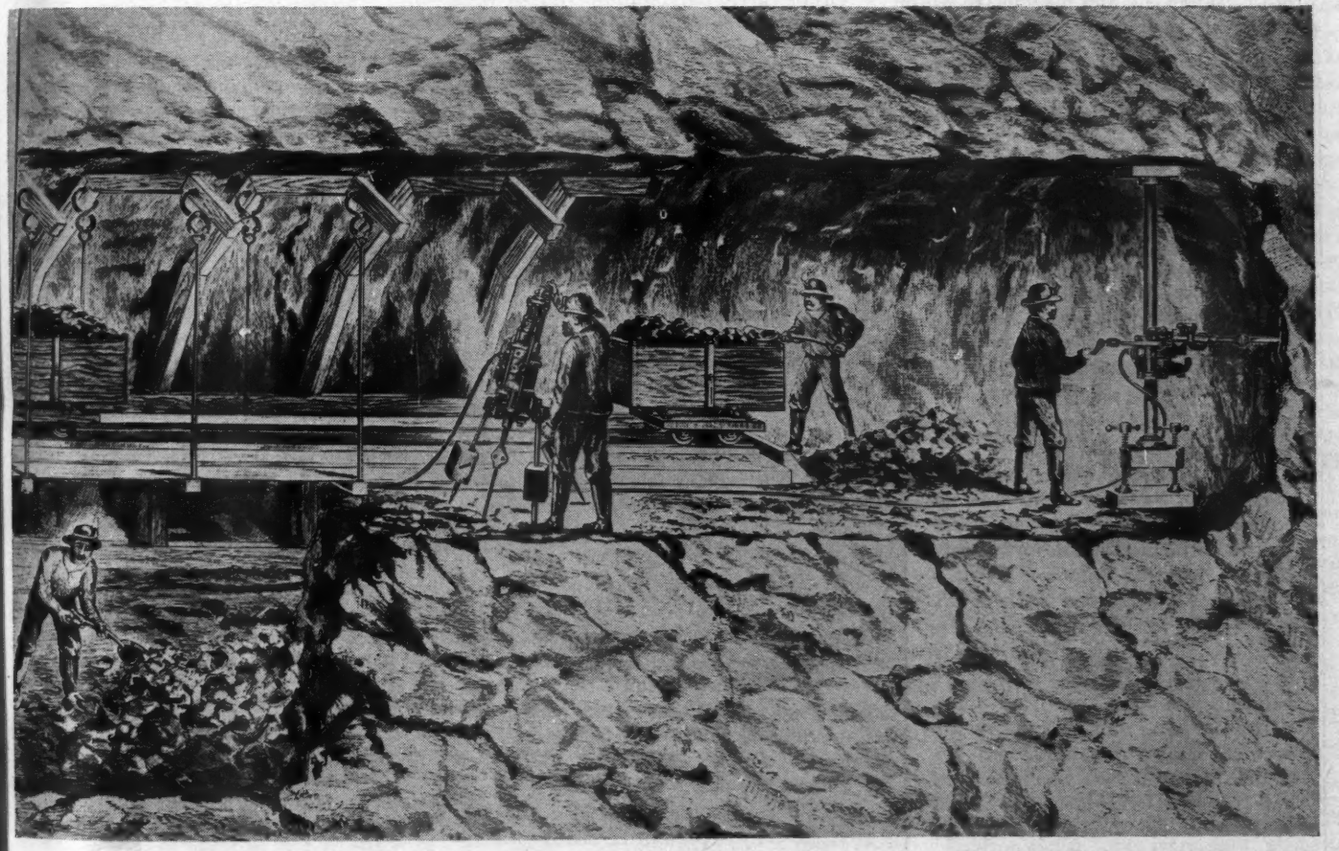
that permitted gouging into the face a few inches with gads and other crude tools. But in harder rocks, the openings that provided entry for prying implements were made with tubular drills and saws fed with emery powder or some other abrasive. There were no explosives available, but the rock was sometimes ruptured by inserting wooden plugs in bored holes and then wetting them to cause them to expand. The Romans were the first to sink shafts to intermediate points along a tunnel line to increase the number of working faces. On the Lake Fucino bore there were 40 such shafts through which the spoils were hoisted in copper buckets with windlasses. This undertaking was completed in 52 A.D., after up to 30,000 men had labored on it eleven years.

In the Middle Ages tunneling was done for military purposes, seldom for public works. Each castle had a secret underground passageway to permit escape in the face of capture or to bring in supplies when besieged. Roman methods persisted without improvement until gunpowder came into use on the Languedoc Tunnel in France, 1679-81. That bore was 510 feet long, 22x29 feet in cross section, and was driven through tufa.

The advent of explosives gave an impetus to tunneling in building canals in France and England, and this work became more active when railroads made their appearance. The first rail bores were on the Liverpool & Manchester Railway in England, 1820-26, and during the next 40 years British lines constructed 45 tunnels having an aggregate length of 40 miles. All these were drilled by hand. The pioneer American canal tunnel was excavated for the Schuylkill Canal at Auburn, Pa., in 1820. It was 20x18 feet in cross section and 820 feet long. The second, which is still in existence, is the 720-foot bore on the Union Canal near Lebanon, Pa. The first American railroad tunnel was driven from 1831-33 for the Allegheny Portage Railroad in Pennsylvania. It was 901 feet long, 25 feet wide by 21 feet high, and was lined with 18 inches of masonry. These early passageways were called "horizontal wells," and were dug almost entirely by hand. Until machinery and ventilating equipment were developed it was not possible to drive long bores without intermediate shafts.

Modern tunneling started with the 8-mile Mont Cenis railroad bore through the Alps, which marked the first use of mechanical rock drills on a large undertaking. Giuseppe Medail, a Swiss peasant, broached the tunnel idea in 1838; but, because of the difficulties involved, work was not started until 1857. Meanwhile, rock drills had been invented, but they were operated by steam, which was not suitable for service in long underground passages. In 1852, Doctor Colladon suggested using compressed air for the drills, and this was done, as is told in the articles on compressors and rock drills in this issue. Following the Mont Cenis, four additional Alpine railroad tunnels were built: St. Gothard, 1872-82; Arlberg, 1880-83; Simplon, 1898-1905; and Loetschberg, 1906-11. The Simplon was notable for having been the longest bore (12.4 miles) ever driven from only two headings until the 13.1-mile Alva B. Adams Tunnel, which extends through the Continental Divide in Colorado, was completed in June, 1944.

The American counterpart of the Mont Cenis was the Hoosac Tunnel, a 4¾-mile bore in Massachusetts. Lacking power drills and other machinery, our first railroads were built to avoid deep cuts and tunnels and therefore followed circuitous routes. Many of them were subsequently straightened and shortened. One of these early roads was the Boston & Albany, which climbed the hills of western Massachusetts by a roundabout course. It be-



NIAGARA TUNNEL

Section through a 7250-foot tunnel that was driven at Niagara Falls in 1890 in connection with a hydroelectric-power project. Note the arrangement that permitted advancing the top heading and bench at the same time and the use of a tripod-mounted drill at the bench. Twenty-five Rand drills were utilized. The drawing appeared in Appleton's "Cyclopaedia of Applied Mechanics," published in 1892.

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MONT CENIS DRILL CARRIAGE

Although it was the first one ever used, this carriage had many of the features of modern ones. Note the air manifold (upper-left) with a hose running to each of the four drills. In old descriptions of the tunnel project the drills were called "perforators."

came so prosperous that a more direct competing line that involved tunneling was planned. Considering that a passageway of the length contemplated had never been driven in the United States, it was a daring undertaking. It was begun in 1858 with hand drilling, and progress was so slow that Oliver Wendell Holmes wrote: "When the first locomotive wheel rolls through the Hoosac Tunnel bore .... then order your ascension robe." The work was started by private contractors who had to give it up in 1862, when it was taken over by the state. As chief engineer, Herman Haupt introduced Burleigh rock drills there in 1866 and nitroglycerine a little later. The project was brought to conclusion in 1874.

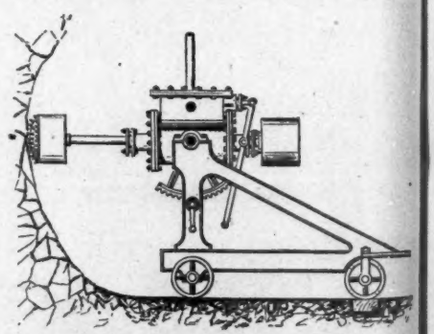
Other early, outstanding tunnels were the Sutro in Nevada and the Musconetcong in New Jersey. The Sutro was driven between 1869 and 1878 to drain the mines of the Comstock Lode and was 20,351 feet long and 12x16 feet in cross section. It was begun with Burleigh drills, which were later replaced by machines of the Ingersoll type. The Musconetcong Tunnel, on the Lehigh Valley Railroad, was 26x21 feet in section and 4829 feet long. Two drill carriages, each mounting three Ingersoll drills, were used at each of its two headings. As both portals were at a considerable distance from a railroad, twenty-four 4-horse teams were engaged in hauling coal for the steam-driven equipment. The bore was completed in 1875 after three years of work.

From those beginnings, rock tunneling has expanded into a major construction enterprise, and there has been a concurrent growth of the art in the mining industry. Just how much the rock drill and other mechanical devices have contributed to this progress is epitomized by the history of the New York water-supply system. The first Croton Aqueduct, completed about 1842, was built by hand. Consequently, it was mostly above ground, which entailed lengthening it by some 7 or 8 miles. Tunnels were undertaken only when they could not be avoided, and aggregated only 4 percent of the total conduit. The pipes were carried across the Harlem River on High Bridge, a $1,000,000 masonry structure that is still one of the finest examples of its kind in America.

When the second or "New" Croton Aqueduct was constructed in 1885-90, the contractors had the benefit of rock drills. The project included 39 miles of tunnels, and because of its 40 shafts and 80 headings served as a valuable drilling school. Instead of bridging the Harlem, the line was run under the stream by means of an inverted siphon that embodied a 300-foot-deep shaft on each side.

The Catskill Aqueduct had the advantage of better drills, and progress on that job was consequently faster. Drilling and other demands for air power were on such a scale that 65 compressors were needed to deliver 100,000 cubic feet of air per minute. Finally came the Delaware River Aqueduct, with 85 miles of continuous tunnels which were driven at speeds that would have been considered impossible when the first Croton system was under construction.

In the field of subaqueous tunneling, compressed air has been of vital importance. It is conceivable that rock boring could be carried on without it; but not underwater work of that nature. Modern submarine tunneling started with the invention of the shield by Marc Brunel of England in 1818. He used it to drive the first passageway under the Thames River, 1825-42. Compressed air was not employed by Brunel, although the same Doctor Colladon who was responsible for its application in the Mont Cenis Tunnel suggested that he do so. The river broke in on the work twice, and so many difficulties were encountered that no one had the courage to attempt subaqueous tunneling during the next 37 years. Meanwhile other shields were invented, although the word "shield" was not applied to that form of steelwork until R.



TUNNELING MACHINE

Much time and money were spent by early inventors on futile efforts to devise a mechanism that would tunnel rock without drilling blast holes. The one illustrated was described in Appleton's 1878 "Cyclopaedia" as Penrice's "battering ram tunnel-borer, which works on the principle of a steam hammer. By suitable mounting of the cylinder on the trunnions of a gun-carriage, it can be made to take all the positions of a siege gun, and strike the rock with blows of 8 or 10 tons energy. The hammer weighs 2½ tons." The ram head, fitted with cutters, was reciprocated by a compressed-air cylinder.

HOOSAC TURKISH BATH

STEAM was used for driving many of the early rock drills because it was the prevailing form of power at the time. The first extensive application of air in America for drilling was in 1866 at the Hoosac Tunnel in Massachusetts, where some of the workmen thought steam would be better and said so. Thomas Doane, chief engineer on the job, told years later how he won the men over to air.

"In the central shaft, when we were down 74 feet, there was no source of air, but we had three boilers to furnish steam for operating the hoisting engines. A drill was set up on a tripod in the shaft bottom and worked with steam. To condense the exhaust steam, it was run through a hose into water that had accumulated on the shaft bottom. After a time, the water became boiling hot and sent up clouds of steam that was annoying and impeded vision. The drills could not be directed properly. After a few hours of this, everybody was convinced that air was preferable and no more talk about steam was heard."

Morton used it in describing one that he had patented in 1866.

A. E. Beach, then editor of the *Scientific American*, was the next man after Brunel to drive a shield tunnel. This was a passageway in New York City under Broadway, between Warren and Murray Streets, in which he proposed to operate a pneumatic-tube railroad. He utilized a shield of his own design that was 8 feet in diameter. It was the first one to be pushed forward by hydraulic jacks, Brunel having employed screw jacks. Beach's railroad was opened in 1870, but the public didn't fancy it. His type of shield served later in tunnel work in Cincinnati and Cleveland.

Underwater tunneling became practicable when compressed air and the shield were used in conjunction. This was brought about through the invention, in 1830, by Admiral Sir Thomas Cochrane of England of what was in fact an air lock. It was initially tried out by the French Engineer Triger in sinking an iron-lined coal-mine shaft at Chalons, France, in 1839, and it was first called an air lock in a description by J. Hughes in 1851 of the caisson-sinking operations for the Rochester Bridge in England. Previously it had been known as a "cell."

The use of compressed air in subaqueous tunneling was initiated simultaneously in Antwerp, Belgium, and New York City in 1879. In Antwerp, an engineer named Hersent drove a small, cast-iron-lined tunnel in connection with some dock work. In New York, DeWitt C. Haskin started operations under the Hudson River on what is now one of the tubes of the Hudson & Manhattan Railroad. Haskin had come to New York from San Francisco, Calif., where he had made a sizable fortune. On the way he had stopped off at Omaha, Neb., and had seen how caissons, made of iron rings bolted together, were being employed in sinking foundations for bridge piers. He conceived the idea of extending similar rings in a horizontal direction from a shaft bottom. He did not use a shield, and the large size of the twin bores—18x16 feet—made the scheme impractical. In 1880 the river broke in, trapping a number of men. The work was suspended until 1882, when it was abandoned because Haskin's money was exhausted.

The undertaking was revived in 1889 by an English company, with Baker and Greathead as consulting engineers. Greathead was the foremost shield tunneler in the world at the time. Progress was made, but operations were terminated in 1891 by a lack of capital. It was during that period that E. W. Moir introduced the hospital lock, which has practically eliminated fatalities from compressed-air illness, or the "bends," which had previously taken a toll among workers of as high as 25 percent per year. In 1902 work was again resumed, this time under a company headed by William G. McAdoo, and the second of the twin tubes was completed in 1904.

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VENTILATING BELLOWS

A hand-operated apparatus for forcing fresh air into a tunnel, as pictured in Agricola's "De re Metallica" of 1556. The development of modern ventilating equipment began with the application of aspirators at the Mont Cenis Tunnel.

SIMPLON MEDAL

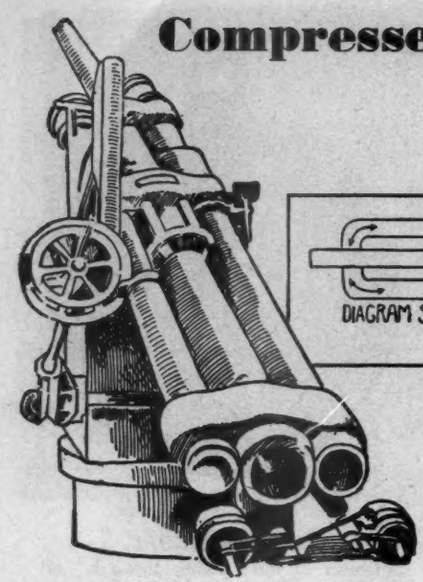
Souvenir of the "holing through" of the Simplon Tunnel in 1903, depicting workmen greeting one another after the two headings met.

Technologically, the effort succeeded because it was directed by Charles M. Jacobs, an English expert who had come to this country as adviser to Austin Corbin who, as president of the Long Island Railroad, had plans for some rapid-transit construction. These were abandoned when Corbin died, whereupon Jacobs assumed charge of the driving of a tunnel under the East River to carry gas mains of the East River Gas Company from Ravenswood, Long Island, to Seventy-first Street, Manhattan. After completing that and the Hudson & Manhattan tubes he built other ones in New York for the Pennsylvania Railroad.

The first combined use of a shield and compressed air in tunneling was in connection with the original section of the London & Southwark subway in 1886. Greathead was the chief engineer. The shield, however, was not of the kind designed purposely for service in conjunction with air. The first of the latter type were employed both in England and in America in 1888. The English operation was the Vyrny Aqueduct under the River Mersey near Liverpool. Over here, J. Hobson designed a shield with which to drive the Sarnia Tunnel under the St. Clair River to carry railway tracks between the United States and Canada.

New York City has been, and still is, the scene of the greatest concentration of subaqueous tunneling. Since the first Hudson River tubes were built, numerous others have been driven for subways and highways. At present, sandhogs are at work there again, pushing a vehicular tunnel under the harbor between Manhattan and Brooklyn.

Compressed-Air Guns



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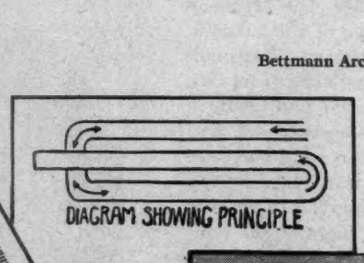
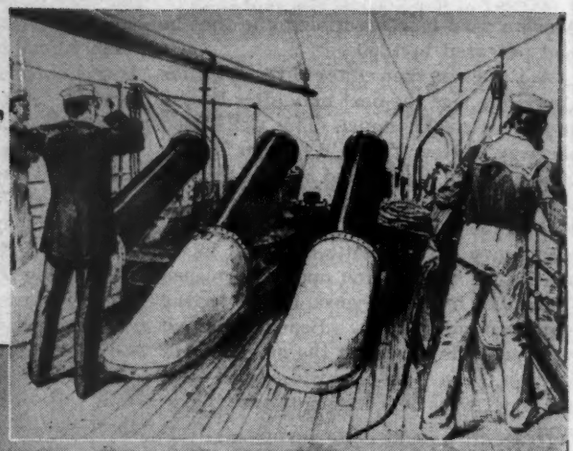
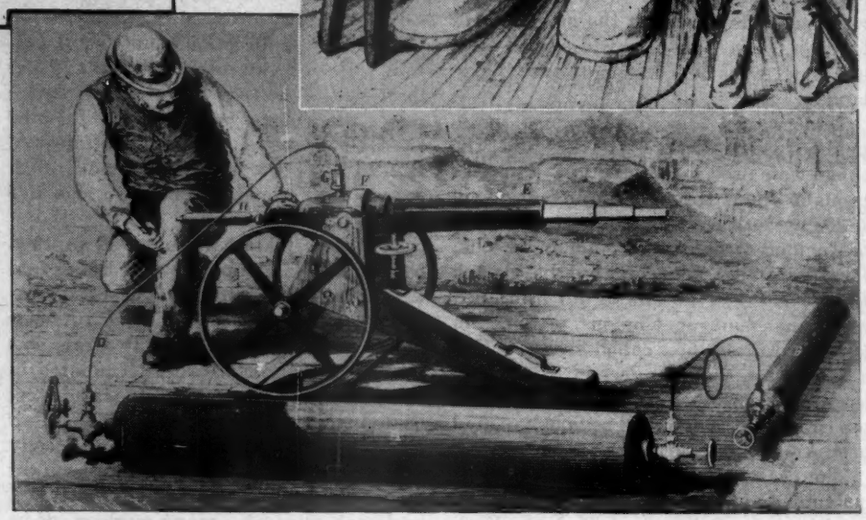






SPANISH-AMERICAN WAR MODELS

At the upper-left is a sketch showing a Sims-Dudley gun, which compressed its own firing air. Pneumatic guns aboard the cruiser "Vesuvius" are pictured at the top-right. As these weapons were virtually noiseless, their advocates made the point that "the first intimation the enemy has of their coming into action is the bursting of the shell in their midst." The other is an experimental "vaporic" gun.

THE *Encyclopaedia Britannica* mentions a crossbow of Ctesibius "which was geared by pistons working in cylinders filled with compressed air." The weapon appeared during the decline of Alexander the Great's Macedonian Army and is reported to have been a contributing factor thereto.

Philon of Byzantium, in his *Natural History*, wrote of the invention by Ctesibius's pupil Hero of a tube out of which an arrow was shot by compressed air. More than sixteen centuries later, in 1560, an air gun was invented for shooting metal balls. The butt end of the latter weapon had a hollowed-out metal reservoir which was charged with compressed air from a force pump. The bullets were placed in a receptacle having a stopcock for admitting them, one at a time, into the barrel. We have no description of how the gun was fired, but there is mention that the propulsive force diminished as the supply of air was depleted, making it necessary to replenish it after a few discharges.

Those weapons were the precursors of various types of air guns that appeared just prior to 1900. At least one of them, the Sims-Dudley, served as a field weapon in the Spanish-American War. In the advance of the "Rough Riders" on Santiago it was fired twenty times by one regiment, and others also used it. It was popularly known as a "dynamite gun" because it threw a projectile charged with Nobel's gelatine. Powder could not be applied directly because the concussion following the blast would have detonated the projectile.

The Sims-Dudley produced its own compressed air through the explosion of a small quantity of smokeless powder. The weapon was constructed in the form of a long tube bent on itself to form three parallel barrels, with the central one the firing tube. The flanking barrels were connected at their front ends. The back end of one of them was connected to the rear end of the firing tube, while that of the other one was fitted with a breech mechanism to receive the powder charge. The projectile was placed in the breech of the central barrel, which was then locked. The powder was next inserted in the proper side tube, and that was locked. When that charge was ignited it generated gases which, in expanding, drove the air in the connected tubes before it, compressing it. It was this force that was exerted against the projectile to propel it.

The gun had a bore of 2½ inches, was 14 feet long, and fired a 36-inch projectile that weighed 11½ pounds when loaded. The missile contained 4 pounds of dynamite and was equipped with a Merriam fuse to detonate the charge upon impact. The associate compression tubes were 7 feet long and had 4½-inch bores. The weapon's range was 1½ to 2 miles and the cost of firing it was $35, or a fraction of that incurred in discharging guns that used powder alone. Complete, the weapon weighed 1044 pounds and was built so that it could be dismantled for transport on mule back. In case of capture, it could be made inoperative by carrying off the cap from one of the tubes, or removing the breech mechanism.

The cruiser *Vesuvius* was equipped during the same period with three compressed-air guns, each 55 feet long. Their barrels were inclined at an angle of 18° and were immovable. The weapons were aimed by maneuvering the ship with its steering gear. The projectiles weighed from 400 to 1000 pounds each, and contained from 200 to 500 pounds of guncotton or gelatine dynamite. The range of a given missile was varied by altering the pressure. The air was supplied by a mechanical compressor, and the maximum pressure applied was 1000 pounds. A shell carrying 500 pounds of explosive could be fired a mile, and one with 200 pounds had a maximum carry of 3000 yards. Similar guns, but capable of being elevated and trained, were developed for coast defense and were called compressed-air torpedo guns. Five were manufactured and set up experimentally at Sandy Hook and San Francisco.

A large naval rifle, designed to be fired with air at 1000 pounds pressure, was placed aboard the Brazilian cruiser *Nictheroy*, and a 3-stage compressor provided the air. One of our 1900 issues offered this comment on it: "The result of this bold experiment in naval armament is being watched with interest. The success of the *Nictheroy* means nothing less than a revolution in naval construction."

A Pioneer in Gas-Turbine Research

IN VIEW of the progress that has been made recently in the development of commercial gas turbines, the following item that appeared in the October, 1903, issue of *Machinery* is of interest:

"In connection with a discussion on the steam turbine at the Master Mechanics' Convention at Saratoga, Professor Hibbard of Cornell University announced that there were prospects of developments in the field of the gas turbine at the General Electric Company's works, Schenectady. A gentleman who recently received an advanced degree at a Western university, in virtue of a very thorough investigation of the subject of the gas turbine, is now in the employ of the General Electric Company, and the inference is that he will have at his disposal the extensive facilities of this company for conducting experiments that may eventually lead to a successful gas turbine. The gentleman is Mr. Sanford A. Moss, who has made a special study of the subject of gas turbines since 1898. The perfection of the gas turbine will not be an easy proposition. It will either have to be accomplished by individuals, working in a haphazard way through a long period of years, or by the concentrated efforts of some large firm like the General Electric Company. The latter plan will undoubtedly result in the quicker solution of the problem."

DR. SANFORD A. MOSS

These are prophetic words, for the gas turbine has been brought to its present status through years of research by large concerns. Sanford A. Moss had a hand in this development, but he is better known for the airplane-engine supercharger which he nurtured in the course of the intervening years. This was more or less of a scientific plaything for a long time, but during the recent war it served to give our military planes additional speed and flying range that were of vital importance. Several large factories were devoted exclusively to the manufacture of this device.

For his turbo-supercharger research, honors have been heaped on Doctor Moss (he received a Ph.D. degree from Cornell University in 1903 and was awarded an honorary LL.D. by the University of California in 1944). These include the 1940 Collier Aviation Trophy, the 1943 Sylvanus Albert Reed prize of the Institute of Aeronautical Sciences, and one of the General Electric Company's Coffin awards.

Initial High-Pressure Gas Line Laid in 1892

THE nation's first compressor station for transmitting natural gas is believed to have been erected by Charles E. Hequembourg of Dunkirk, N. Y., a pioneer natural-gas engineer. It was located at Rixford, Pa., and pumped 6,000,000 cubic feet of gas daily to Bradford through 11 miles of 7-inch cast-iron pipe. The original compressor was a duplex steam-driven unit with 24-inch steam cylinders, 26-inch compression cylinders, and a 30-inch stroke. Our source of information did not state when this plant went into service.

The pioneer high-pressure station was built at Greentown, Ind., in 1892. It pumped natural gas to Chicago, Ill., through 120 miles of 8-inch line. The system was designed to operate at 600 pounds pressure, but this figure was never attained. Before the line was completed the gas was compressed to 700 pounds pressure and shipped to Chicago in large cylinders.

BOOSTED ROCK DRILLS

JOHN D. CRIMMINS was reported to have been the first contractor to apply the rock drill on a large scale to other than tunnel work. He built a sizable part of the second Croton Aqueduct, made excavations for gas tanks for many companies, constructed much of the first elevated railway in New York, laid the cable railway in Broadway, and erected many large hospitals, churches, and business structures. At one time he had 12,000 men working for him. Mr. Crimmins died in 1917.

Elevator Dropped in Test

THE idea of checking the descent of a passenger elevator with an air cushion at the shaft bottom originated with Dr. F. T. Ellithorpe, who afterward organized the Ellithorpe Safety Air Cushion Company. In 1902 a unique test of the device was made at the 500-foot City Hall Tower in Philadelphia, which was then the tallest building ever to be erected. A passenger car, weighing 2500 pounds, was allowed to drop from a height of 290 feet into a well-like chamber that extended upward 75 feet from the bottom. Upon entering this zone, the car compressed the air below it, thereby checking its speed gradually.

In the cage were placed a lighted lantern, six rats, 50 light bulbs, and several dozen eggs, and all survived without appreciable damage. A New York newspaper reporter was refused permission to make the descent. Doctor Ellithorpe dropped six stories several times and suffered no injury. It was computed, however, that, in the case of the Philadelphia test, a 150-pound man would experience an upward thrust of 720 pounds on the soles of his shoes when the car reached the well and probably double that at the instant of stopping. The pressure on the hip joints was figured to be about two-thirds as much. Under such conditions he would probably collapse, but he would escape the fatal results of an uncushioned drop.

COMPRESSED OXYGEN USED BY DOCTORS IN 1880's

IN HIS book, *The Vanished Pomps of Yesterday*, Lord Frederic Hamilton, British diplomat, describes the use of compressed oxygen in treating Empress Alexandrovna of Russia, the invalid wife of Alexander II (1818-1881): "The empress," he wrote, "appeared but very rarely. It was a matter of common knowledge that she was suffering from an incurable disease. All the rooms in which she lived were artificially impregnated with oxygen, continuously released from cylinders in which the gas had been compressed. This, though it relieved the lungs of the sufferer, proved very trying to the Empress's ladies-in-waiting, as this artificial atmosphere with its excess of oxygen after an hour or so gave them all violent headaches and attacks of giddiness." This was in the early 1880's.

This and That

Life in 1896

WHEN our first issue appeared, 50 years ago this month, life was much different than it is now. Manufacturing, as we know it today, was in its infancy. The 5000-hp. hydroelectric generating station at Niagara Falls was the largest power plant in the country. In the previous year only four automobiles were registered in the nation. Ready-to-wear clothing was not to be had. Motion pictures of the silent, flickering type had been shown for less than a year. Reinforced concrete was virtually unknown. The electric refrigerator and the radio were unforeseen, and the historic first flight of the Wright Brothers was five years in the future. Few workers had Saturday afternoons off; the work week consisted of six days of ten hours each. Nylons were undreamed of, and one pair of silk stockings was sold each year for every 2000 persons in the country. The great Texas oil fields had not been discovered, radium and helium were unknown, and high-speed tool steel had not been developed. Vacuum cleaners, tungsten electric lights, electric irons, and diesel engines had not yet appeared.

In 1900

THE Westinghouse Air Brake Company advertised that more than 1,250,000 of its brakes were in service on the nation's railroads. W. K. Vanderbilt, Jr., drove his French automobile from Newport to Boston and return—160 miles in 3 hours, 57 minutes. Workmen at Cornell Dam, Croton, N. Y., struck for an increase in wages from $1.25 to $1.50 a day.

In 1903

THE following appeared in the London *Daily News*. "Many of us scarcely realize the importance of compressed air. It may therefore be described as the inspiration of a football or a Dunlop tire. It is, moreover, compressed air which breathes manifold music from the souls of organs, and which lends rotundity to the cheeks of Sousa's performance on the trombone."

Tunnel Ventilation

BEFORE air compressors became generally available, some tunneling was done with steam-operated rock drills and great difficulty was experienced in ventilating the headings. Once excavating had advanced a little distance from the portal, the workings grew uncomfortably hot from the exhaust steam of the machines. A Colorado miner devised a simple ventilating system that partially overcame this condition. Near his steam boiler at the portal he set up a wooden box chimney to the bottom of which he connected wooden piping that extended into the tunnel and close to the face. In the open end of this conduit was inserted a wide-mouthed funnel arrangement which was removed before blasting. After a shot was fired, a ¼-inch steam line running from the boiler to the outside chimney was opened. This induced a strong current of air, which drew the smoke and gases out of the passageway and caused fresh air to flow in to replace it. When drilling was resumed, the outside steam jet was shut down and the exhaust steam from the drills was piped into the funnel in the end of the pipe, thus causing a draft that brought in fresh air. This same system was used years later by contractors on the South Penn Railway tunnels until they could procure air compressors to run their drills.

Rites Silenced Subway

JOHN B. McDONALD, who built New York's first subway, came to this country from Ireland when he was a boy. During the latter years of his life he received an annual salary of $50,000 from the Interborough-Metropolitan Company, which operated the underground railroad system. When he died, funeral services were conducted at St. Patrick's Cathedral on Fifth Avenue. At the instant that the casket was being borne from the church the power in all the city's subways was shut off and all traffic stopped for one minute.

Birth of Rayon

IN MARCH of 1893, the United States Consul at St. Etienne, France, reported the discovery by Count de Chardonnet of a process for making silk (also called cellulose silk) from wood pulp. Compressed air was used in the process to force collodion (viscose) through a filter. It was reported that "The principal defects at present are said to be inequality of the product, inflammability, and the snapping of the thread. It is claimed, however, that all these difficulties can be overcome." In 1899, the artificial silk produced in the United States had a value of $10,380.

Origin of Metallizing

THE inventor of the metallizing gun, M. U. Schoop, left his native Russia to live in Switzerland. He got the idea for his apparatus watching lead bullets, fired from a Flobert rifle, spatter against a metal surface. His first experiments consisted in shooting tin and lead pellets against iron plates with a small cannon that he had made. After a time he thought out the scheme of projecting molten metals in an air stream. He first used pressure in the range of 500-600 pounds, then gradually reduced it to 40 pounds.

Torpedo History

THE modern automobile torpedo was the offshoot of a scheme to build a small, crewless surface bomb boat. Captain Luppis of the Austrian Navy conceived the idea and enlisted the aid of Robert Whitehead, an English engineer, in 1864. After the two had worked jointly for two years they brought out the compressed-air torpedo that has played a vital part in naval warfare. The first Whitehead-Luppis was driven by compressed air stored in a tank at 368 pounds pressure.

Industrial Lighting

AROUND 1896 many factories were lighted by lamps that were known by various names such as Wells, Lucigen, etc. In all of them, a stream of compressed air forced oil through a nozzle, forming a spray which, when ignited, produced a flame 5 inches in diameter, 30 inches long, and of 1000 candlepower intensity.

Improved Drilling

THE introduction of the mechanical drill-steel sharpener brought about a great change in rock-drilling practice. Prior to its appearance, the tendency was to get the last bit of work possible from a drill bit because resharpening by hand was a laborious and expensive job. Consequently, to save blacksmithing, much drilling was done with dull bits and progress was slowed down. With the mechanical sharpener better steels were made quickly at comparatively low cost and faster drilling of better holes resulted.

Drill Durability

A FEW scattered statistics indicate the enormous strides that have been made in building rock drills that "can take it." In the Mont Cenis Tunnel, which was the cradle of mechanical drill testing, 200 machines had to be kept on hand to make sure that there would be sixteen at the drilling faces at all times. In the Hoosac Tunnel, pioneer American machine-drilled bore, there were three drills in the repair shop for every one at the heading. In the St. Gothard Tunnel, the average time a drill could be used before it required attention was 24 hours. Coming down to modern times, we find a different story. The 1000 Palms Tunnel of the Metropolitan Aqueduct was driven in 1935-36 with N-75 drifter drills that had previously seen two years of service. Nevertheless, a record of 1101 feet of advance from one heading was set in November, 1935. In the 13.1-mile Alva B. Adams Tunnel in Colorado, which was holed through on June 10, 1944, all but 6600 feet was driven with 28 Ingersoll-Rand DA-35 power-feed drifters. All the original drills were still in service up to the time of the final blast.

Pneumatic Oddities

MANY queer and sometimes chimerical schemes have been advanced for employing compressed air. There have also been incidents involving compressed air that had their unusual or humorous side. The following items are indicative of what we mean.

Our May, 1904, issue reported that "Peter Nissen of Chicago has invented a pneumatic barrel designed to sail on the water. It is a curious contrivance, 32 feet long and 22 feet in diameter, with a maximum circumference of more than 60 feet. It is shaped somewhat like a football. After being inflated with air, it is expected that the wind will roll it across the water. Suspended from a shaft running through the barrel is a rowboat in which the passengers ride. The boat is used so the passengers may be able to row ashore if anything happens to the barrel." What became of it was succinctly told in our July, 1904, issue: "When given a trial on Lake Michigan, it simply floated across the water and refused to roll."

The idea of protective hard hats for construction workers is said to have stemmed from the helmets worn by troops in World War I. However, there was a strong suggestion of the trend in the following item from our July, 1914, issue: "A New York contractor always wears a derby hat in tunnel work because it acts as a bumper and often saves his head a knock in dark and crowded quarters."

In April, 1904, a resident of Connecticut patented a device to keep trolley tracks clear. He proposed mounting a tank, charged with compressed air, underneath each car and running pipes from it to the front end. When the motorman depressed a button with his foot a valve would be opened, and the resultant blast of air was supposed to blow the obstruction off the track.

Compressed air fender
(From our May,1896, issue)

While touring Italy in 1898, an Albany, N. Y., man saw and bought a pneumatic horse collar in Milan. It had been awarded first prize at the 1895 Milan exhibition by the Society for the Prevention of Cruelty to Animals. Because of its lightness, it did not cause galling and chafing. The Albany man placed it on display in a livery stable in his city, where it received the approval of horsemen. Subsequently, several pneumatic horse-collar companies were organized in this country. One was located in Holland, Mich., in 1902.

SLEEPING ON AIR

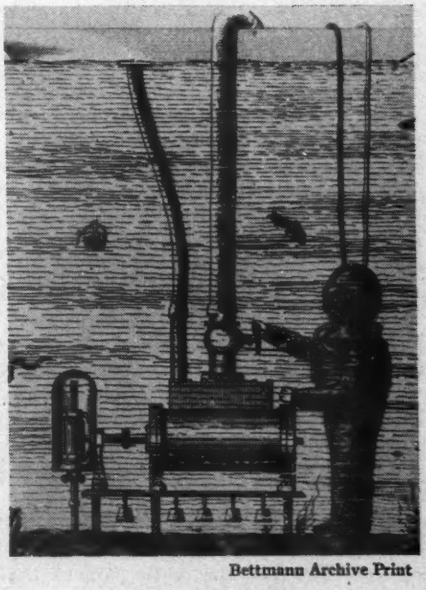
Fifty years ago, inflatable beds and pillows promised to become popular. Pullman cars were designed to use mattresses and pillows that could be blown up at night and deflated and put away in a small space by day. In 1893, the private car of a vice-president of the Pittsburgh & Lake Erie Railroad was provided with them and also with air-filled chair seats. At the time, the idea was hailed as something new, but it was actually about 1700 years old, as this picture shows. It illustrates soldiers of the Roman emperor Heliogabalus resting on an air-blown bag. At the lower left-hand corner may be seen the bellows with which it was inflated. History records that Heliogabalus, who was born Varius Avitus, was very popular with his troops, and we can well believe it after looking at the picture. When still a boy, he was appointed high priest of the Syrian sun god Elagabalus, and while serving in that capacity at the Port of Emesa his soldiers started an insurrection that carried him into the emperor's seat, where he served as Marcus Aurelius Antoninus. He provided de luxe inflated bags for his guests to recline on at banquets, and is reported to have amused himself by suddenly letting the air out of them and precipitating the individuals onto the floor. We are not told whether this prank had anything to do with the wane of his popularity; but, in any event, he was slain in 222 A.D. after a reign of only four years. The illustration originally appeared in a book by Flavius Vegetius Renatus, a fourth-century writer on military subjects.

The following appeared in our November, 1911, issue: "The lung capacity of the average woman who does not wear corsets is about 171 cubic inches; of one who is in the habit of wearing corsets, only 134 cubic inches."

In 1900, M. W. Quick patented a system for conveying air at 14-17 pounds pressure to oil wells to operate pumps. The expanded air was piped back to the compressor. According to the inventor, "This prevented meteorological changes in the atmosphere from interfering with either compressor or motors."

In May, 1904, Israel Hogeland of Indianapolis, Ind., was reported to have invented a portable compressed-air elevator to raise firemen and their apparatus to the upper floors of burning buildings and to rescue trapped persons.

From an August, 1904, issue of the New York *Sun*: "Compressed air is beginning to be very useful in the best of the barber shops. The air does almost everything from serving as a brush after a haircut down to blowing excess powder off the customer's nose. The tubes connected with the main source of air supply



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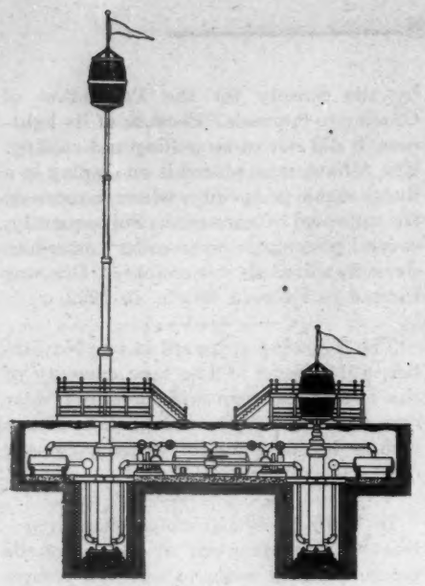
SUBMARINE DRILL

An early inventor's scheme that was never adopted.



PNEUMATIC JOY RIDE

In 1904, the Pneumatic Tower & Elevator Company was organized to build the amusement device shown above. A Chicago man, who hoped also to apply the idea to passenger elevators, was the patentee. It was supposed to work as follows: Compressed air introduced inside telescoping tubes elevated a passenger compartment to a height of 125 feet. The compartment, which accommodated 25 persons, then revolved so that the passengers, remaining seated, could obtain a panoramic view. The towers operated in pairs, so that one ascended while the other descended. The compressor and other machinery were located underground. The cost of the structure was estimated at $20,000. It is not of record whether one was ever built.

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hang by every barber's chair now in the best equipped shops."

Persons who play billiards and pocket billiards know that unless there is plenty of elbowroom, the cue, when drawn backward to make a shot, may encounter interference in the form of a wall, furniture, or a player at an adjoining table. In an effort to overcome this drawback and to permit tables to be placed in rooms affording little clearance, a 1905 inventor devised a pneumatic cue. In announcing its advent, the *Philadelphia Record* said: "It includes a short, hollow stick, provided at one end with a movable tip and at the other with a piston and rubber bulb, which furnishes the propelling power. Pressure upon the bulb will force the cue stick out with any desired degree of force, and the quickness with which the pressure is applied determines the shooting strength, as the harder the ball is hit."

Typewriting in the early part of the century was a bit more onerous than it is now. Copying ink was often used, and when an erasure was made a slip of the

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